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LOUIS PASTEUR (1822-1895)

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PITMAN'S COMMON COMMODITIES
AND INDUSTRIES

ALCOHOL

IN COMMERCE AND INDUSTRY

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PREFACE

Owing to the death of the author whilst this work was passing through the press, it has fallen to a colleague to complete the revision and to write these prefatory remarks.

The text is as the author left it, save only for those few slight amendments and additions which current events rendered necessary. The addendum completes the author's tables and includes the latest published returns.

Mr. Simmonds's exceptional experience of the applications of alcohol to commercial and scientific uses, and his wide and precise knowledge of the subject in all its phases should warrant for this little book recognition as a useful and reliable introduction to a knowledge of the part played by alcohol in industry and commerce. To those who are already cognizant of the great and increasing extent to which alcohol functions in the arts and manufactures, it should also prove helpful, as affording a brief but inclusive survey of the production and applications of a commodity which presents so many features of social, scientific, and economic interest.

Thanks are tendered on behalf of the author to Messrs. Blair, Campbell & McLean, Hall & Co., and Macmillan & Co. for the loan of blocks of the various illustrations.

J. F. H.

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IN COMMERCE AND INDUSTRY

CHAPTER I

INTRODUCTION

HUXLEY once remarked that it was a curious speculation to think what would have become of modern physical science if glass and alcohol had not been easily obtainable. With glass we are not specially concerned here, but the remark is certainly true as regards alcohol. To take only one branch of physical science—namely, chemistry—it is assuredly the fact that, lacking alcohol, the astonishing progress which this branch of knowledge has made during the last few decades would have been quite impossible.

And if this is true of physical science, it is no less true of industry, and therefore of commerce also. Chemistry permeates all our industries. Lord Moulton has recorded that during the great war, when he was deputed to supervise the supplies of explosives, the "omnipresence" of chemistry was a revelation to him. "I had never realized," he says—"I do not suppose many people in England *do* realize—how chemistry permeates every industry that exists, how omnipresent it is in every human effort, how its own prosperity brings prosperity to every other form of human industry. . ." And again: "I had to show to the English people how chemistry went into every portion of its life, and how

the fibres of its rootlets were inextricably mixed with every industrial enterprise."

No doubt Lord Moulton was concerned more especially with chemistry in relation to explosives; but his remarks, it will be seen, are quite general, and they aptly describe the bearing of chemistry upon industry at large. They are true of normal times, and apart altogether from the special *rôle* of chemistry in modern warfare. Both in peace and in war, chemical science is indispensable to our well-being; and its progress and development have been largely dependent upon alcohol.

As regards war, however, we may remark that it was not merely indirectly, by its influence on the general development of chemical and physical science, that alcohol was of importance during the great national struggle. It is a matter of common knowledge that the large distilleries of the country were diverted from their normal activities, and utilized by the State for producing alcohol to be employed directly in the manufacture of explosives and other chemicals, without which the war could not have been carried on at all.

So much then for the importance of alcohol in the ordinary arts of peace and in the making of war. But there is yet another domain, and one of transcendent interest to all, in which the production of alcohol has been allied with progress and with developments having inestimable value for mankind—namely, the relief of human suffering. In this respect, also, very few people realize how great is the debt which the race owes to studies and experiments originating in questions connected with alcohol. We do not speak here of the anaesthetics—ether, chloroform, ethyl chloride, and so on—produced directly from alcohol. Great as have been the benefits which the use of these has

conferred on suffering humanity, they pale almost into insignificance when compared with the developments in medical practice, in surgery, and in modern hygiene which have followed, directly or indirectly, from researches upon the nature of alcoholic fermentation. This process—fermentation—was at one time thought to be a purely chemical one. Yeast was regarded as a chemical reagent, which produced alcohol from sugar by breaking the latter substance down into a simpler body, much in the same way as caustic soda will split off glycerine from fat. Further study showed that yeast was, in fact, a living organism, not a chemical reagent. The microscope revealed it as being made up of very small cells, which, under suitable conditions, could grow, and reproduce like cells to an indefinite extent. Alcoholic fermentation—the decomposition of sugar into alcohol and other products—was intimately connected with, and dependent upon, the vital activity of the cells. But yet further researches showed that there were other kinds of cells, which produced by their vital activities quite other products than the wholesome beer or wine yielded by ordinary yeast. Pasteur, in particular, after studying *normal* alcoholic fermentation, passed on to investigate the abnormal processes which gave rise to unsound beer or wine. These researches, in their turn, led to inquiries into the cause of certain abnormal conditions in animals—namely, into the origin of anthrax, and of certain diseases to which silkworms are liable. Definite proof was obtained that these ailments were due to the action of microscopic living organisms—bacteria—and henceforth the science of medicine was revolutionized. The clue to the real nature of infectious disease was obtained. The possibility of rendering subjects immune from disease could now be visualized, and the prevention of

epidemics foreseen. These researches, in fact, "laid the foundation for the subsequent wonderful developments which have taken place in the spheres of preventive medicine and hygiene"; and they had their origin in the patient and laborious investigations undertaken by many workers with a view to elucidating the natural processes involved in the production of alcohol. As Dr. Horace Brown has well remarked, "modern surgery, like preventive medicine, is a child of the fermentation industries."

Admitting, then, the importance of our subject—alcohol—let us proceed to obtain a fairly definite idea of what this important substance is like. Most people know that it is the intoxicating principle contained in beer, wine, whisky, and other spirituous liquids; but many persons have only a very hazy, indefinite notion as to what it is in appearance, or what its properties, other than those of an intoxicant, are. Assuming, therefore, that the reader has little or no preliminary knowledge of the subject, we will devote a few pages to describing some simple experiments which will enable him to form a clear mental picture of this interesting commodity, and, incidentally, will explain certain technical terms such as "distillation," "specific gravity," and so on.

Suppose we take a quantity of ordinary beer or wine, and distil it. To do this, we boil it in a flask or other vessel, from which the vapours given off by the boiling liquid can be led away through a tube and cooled, thus condensing them into a liquid again. Alcohol, like water, is converted into vapour when boiled, so that the vapours given off by the boiling beer or wine contain a mixture of water-vapour (steam) and alcohol-vapour. Hence the condensed liquid, or "distillate," as it is termed, will contain the alcohol originally present in

the beer or wine, mixed with more or less water, but separated from the sugars, colourings, and other solid matters, which remain behind in the distilling flask. (Besides alcohol and water, the distillate will include traces of oily and other volatile matters, but for the present purpose these can be disregarded.)

If the operation is continued until about two-thirds of the beer or wine has been distilled over, practically all the alcohol will be obtained in the distillate; but as it is still mixed with a large proportion of water, it is only a weak spirit. Note, however, that we have eliminated about one-third of the water. The alcohol is now concentrated into two-thirds of the original bulk.

On re-distilling the distillate in the same manner, part of the water is again eliminated. Repeating this operation as often as may be necessary, we obtain a product in which the proportion of alcohol becomes greater and greater, until eventually the distillate consists mainly of alcohol, with only a very little water remaining.

In practice, various devices are employed to shorten the process by reducing the number of re-distillations required. Some of these devices are described further on. It will suffice here to say that in modern stills alcohol of very high strength (96 per cent or more) is produced at a single distillation. The last traces of water cannot be eliminated by distillation alone, however often repeated; but they can be removed by chemical treatment (*see* later, "absolute" alcohol).

Suppose, then, that we have obtained our final product, either quite free from water or nearly so. It will be a clear, colourless liquid, looking very much like water. One might almost say, however, that the resemblance ends here. On cautiously tasting the

liquid it will be found, unlike water, to have a very pungent flavour ; and its odour, though not very strong, is a pleasant, characteristically " spirituous " one.

Alcohol is a much lighter substance than water, as the following experiment will show. Suppose we have a bottle which, when filled with pure distilled water at the temperature 15·6° C. (= 60° F.), holds exactly 100 grams of the water. If this bottle is filled with pure " absolute " alcohol (that is alcohol entirely freed from water) at the same temperature, it will be found that the weight of the alcohol is only 79·36 grams (more exactly, 79·359). The alcohol, therefore, weighs less than four-fifths as much as the same volume of water.

If we divide the weight of the alcohol by the weight of the water, we obtain $79{\cdot}359 \div 100 = 0{\cdot}79359$. This is the " *specific gravity* " of alcohol at 15·6° C., that is the relative weight of alcohol at this temperature, compared with the weight of the same volume of water at the same temperature. Special bottles are obtainable for such experiments—" specific gravity bottles " or " pyknometers "—arranged so that the determination may be made as accurately as possible.

When a light is applied to it, alcohol readily ignites, burning with a pale blue flame, practically non-luminous, but very hot.

It mixes freely with water, and develops heat in doing so. If about an equal volume of water is stirred into a quantity of alcohol, both being at the ordinary room temperature, the increased warmth of the mixture can be felt even with the hand, and a thermometer will, of course, show it very plainly.

Another important property of alcohol is its power of dissolving many substances which are quite insoluble in water. If, for instance, we powder some resin and shake

it up in a test-tube with water, none will dissolve; but on repeating the experiment with alcohol, the resin can be completely brought into solution. This property is utilized to an enormous extent in the making of varnishes and polishes. Similarly, alcohol will dissolve castor oil (though not other fixed vegetable oils, except to a limited degree). Mixed with ether, it dissolves guncotton to form collodion, extensively used in photography and in medicine. It is also a good solvent for a great many other "organic" compounds. Indeed, it is largely, though not by any means entirely, due to this solvent property that alcohol has proved of such signal service in the development of chemistry, with all that this development implies for the arts and manufactures.

From the foregoing outline the reader will, it is hoped, have gained some definite preliminary ideas as to what alcohol is and what it does; and we may now proceed to a more detailed study of the subject.

Before doing this, however, it may be well to explain that, in chemistry, the term "alcohol" has a wider significance than we have given it in these introductory remarks. It is a generic term, denoting not merely one particular article, but a *class* of substances which have certain chemical properties in common. These substances are therefore all called "alcohols," and there are many members included in the group. They differ from one another in their chemical composition, and also in their physical properties, such as specific gravity, boiling point, solvent power, and so on. The ordinary alcohol of wine, beer, and spirits is only one member of the group, albeit the most important one. It is known as "ethyl" alcohol. Another member of the alcohol class is distilled from wood, and termed "wood spirit" or "methyl" alcohol; this is a liquid resembling

ordinary alcohol in many respects, though in others it is quite different. Other alcohols, termed "propyl," "butyl," and "amyl" alcohols, are found in fusel oil, whilst yet others occur in various essential oils used in perfumery or as flavourings. In general, however, whenever the word "alcohol" is used alone it signifies the ordinary or "ethyl" alcohol. If any of the others are meant, the fact is always indicated by the use of the adjectives methyl, propyl, amyl, etc., unless the context clearly shows this to be unnecessary.

Ethyl alcohol has the chemical formula C_2H_6O. Assuming that the reader has no knowledge of chemistry, it may be explained that this formula indicates (*inter alia*) that alcohol is composed of two atoms of carbon (C), six of hydrogen (H), and one of oxygen (O). The relative weights of these atoms are, respectively, 12, 1, and 16. Hence the composition of ethyl alcohol by weight is—

Carbon . . .	$2 \times 12 =$	24	parts.
Hydrogen . . .	$6 \times 1 =$	6	,,
Oxygen . . .	$1 \times 16 =$	16	,,
Total		46	,,

If, for example, we had 46 ounces of pure alcohol, by weight, this quantity would contain in chemical combination 24 oz. of carbon, 6 oz. of hydrogen, and 16 oz. of oxygen. The *percentage* composition of ethyl alcohol is readily calculated from these figures; it is: carbon 52·1, hydrogen 13·1, and oxygen 34·8 per cent.

The formula C_2H_6O is generally written in a slightly extended form as $C_2H_5{\cdot}OH$, indicating that, as existing in alcohol, one of the hydrogen atoms has different properties from the other five.

Methyl alcohol has the chemical formula CH_4O, or $CH_3{\cdot}OH$. Here, it will be seen, there is only one

atom of carbon, instead of two. Propyl alcohol is represented by C_3H_8O, or $C_3H_7{\cdot}OH$, in which there are three atoms of carbon. The other fusel oil alcohols contain still larger proportions of carbon, and are, with propyl alcohol, often referred to as "higher" alcohols.

It is beyond the scope of this little work to deal much further with these various substances; but as they, and especially methyl alcohol, are in practice often associated with ordinary alcohol, it is well at the outset briefly to indicate the relationships existing between them and ethyl alcohol. Additional particulars will be found in Chapter VIII.

CHAPTER II

THE MANUFACTURE OF ALCOHOL FROM STARCH AND SUGAR MATERIALS

PRACTICALLY all the alcohol of commerce is made by fermentation processes. Other methods are available, as will be noted in due course ; but they are not yet sufficiently developed to be of great importance, although this position may be altered as time goes on. Meanwhile fermentation methods hold the field, and as far as can be seen are likely to do so for an indefinite period.

Materials Used. The substance fermented is always *sugar*, of one kind or another. The raw material which the distiller purchases, however, is not always, or usually, sugar ; but if not, it must first be converted into some form of sugar before actual fermentation can take place.

Chiefly, the distiller's raw material consists of starch-bearing products, such as barley, maize, millet, oats, potatoes, rice, and rye. Sugar products are also used in considerable quantity, especially molasses, glucose, cane sugar juice, beet sugar juice, the sap of various palms, the flowers of the mahua tree, wine, and fruits. In fact almost any substance containing starch or sugar can be utilized for the purpose, if it is available in sufficient quantity and at low enough price. But as starch and sugar are foodstuffs, the market value of particular materials may, at a given time and place, be too high to allow of their being used in the production of alcohol. What is the best material in one country will often be too costly for use in another. Very much depends upon the climate, the kind of soil, the relative cheapness of labour, and the facilities for transport. In this country,

for instance, grain and molasses are chiefly used, potatoes scarcely at all ; whereas in Germany and Russia potatoes are employed for alcohol making on a very large scale. The nature of the soil, and a supply of relatively cheap labour, have made the potato the most economical source of alcohol in those countries ; but in the United Kingdom it has too high a value as food : the distiller cannot pay the price it commands for this purpose. On the other hand, our facilities for overseas transport enable us, in normal times, to obtain molasses, maize, and even rice at a cost low enough to allow of these articles being used in making alcohol. In tropical or sub-tropical countries, again, the most suitable raw materials may be starch-bearing plants like cassava, arrowroot, and maize, or sugar products such as cane juice and palm sap.

The following table shows the average amounts of fermentable carbohydrates, mainly starch, present in the principal starch-bearing materials used in the distilling industry. Naturally there is some variation, according to the qualities employed.

TABLE I

STARCH-CONTENT OF VARIOUS MATERIALS

Material.	*Starch, etc., per cent.*
Barley	60
Maize	63
Oats	53
Rice	67
Rye	63
Wheat	65
Green Malt	40
Dry Malt	68

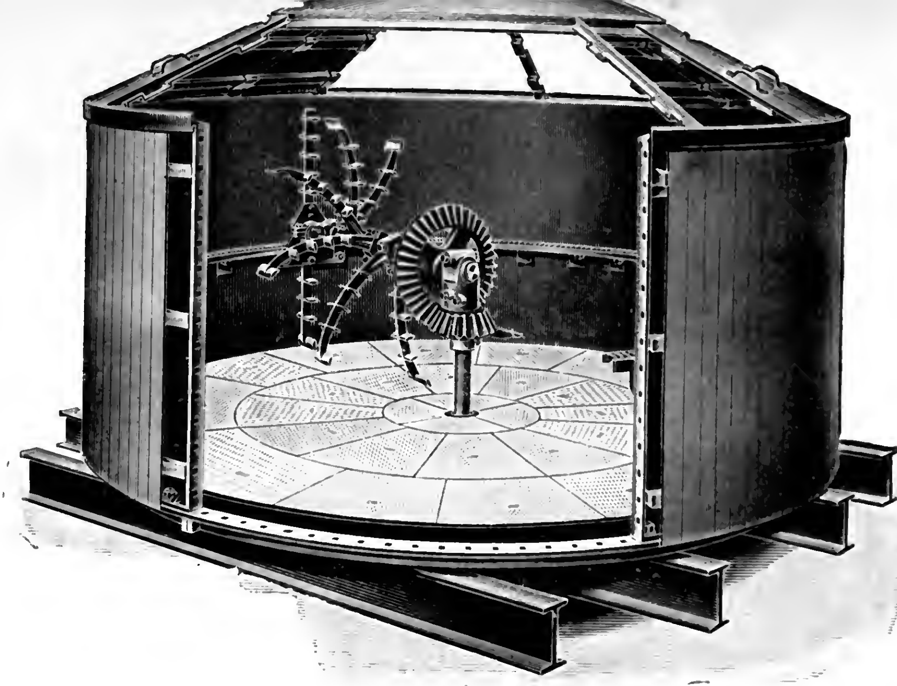
Mashing. The first operation in the process of converting starch substances into alcohol is to obtain a "mash" of these materials. There are some differences of treatment, according to the ingredients employed.

With cereals like malt, barley, oats, and rye, such as are used in this country for making " grain " spirits, the substances, including always malt in proportion ranging from 10 to 25 per cent, are first crushed, and the resulting " grist " is extracted two or three times with hot water (technically termed " liquor"). The last quantity of " liquor," containing only a relatively small quantity of matters extracted from the grains (or " goods "), is used for the first extraction in a subsequent mashing.

Most of the industrial alcohol produced from starch-bearing materials is, however, obtained from potatoes and maize. This procedure, therefore, will be taken as the main theme of the present chapter, and described in some little detail.

If potatoes are being dealt with, they are first washed to free them from adherent soil. Maize may be coarsely ground and soaked in water for a day, or it may be merely mixed with one or two parts of water. The potatoes or maize are then filled into a " cooker " or " converter " —a kind of boiler shaped like an inverted cone—and heated with steam under pressure, in order to gelatinize the starch. The mass is kept stirred, either by means of a stirring apparatus fitted inside the converter, or by blowing in jets of steam or air at the lower part of the vessel. When the steaming is completed, the resulting pulpy mass is blown out from the lower end of the converter into the mash tun.

Saccharification of the Mash. Before the gelatinized starch is blown out, a quantity of ground malt mixed with cold water is placed in the mash tun, which is fitted with a stirring apparatus and a system of cooling pipes fed with cold water. By this means the hot mash is cooled and well mixed with the malt as it enters the tun. The process is so regulated that the temperature



Blair, Campbell & McLean

FIG. 1

MASH TUN FOR CEREALS WITH RAKE STIRRING GEAR

of the mash is kept at or about 55° C. (130° F.) for 20 to 30 minutes. A part of the hot mash, about one-sixth of the whole, is retained in the converter until the end of this period, when it is run out into the main quantity and well mixed with it, in order to raise the temperature of the whole, first to about 62° C. (144° F.), and finally to 68° C. (154° F.).

In this operation the starch is converted into sugar as explained below. When the conversion is finished, the resulting "sweet mash," or "wort," is cooled, passed through some form of strainer to remove solid particles of skin, husk, etc., and run into the fermenting vats or "wash backs." The completion of the change from starch to sugar is ascertained by testing a little of the mash with solution of iodine. As long as any starch remains unchanged, it gives a blue colour with the iodine, due to the formation of iodide of starch. When no such blue colour is obtained the starch has all been transformed.

Theory of the Foregoing Process. The preliminary steaming is for the purpose of softening the starchy material, and thus making it more amenable to attack by certain substances, termed "enzymes," which are present in the malt. The particular enzyme concerned in the transformation of starch to sugar is one known as "diastase" or "amylase." At a temperature of 50°-55° C. (122°-131° F.), diastase acts rapidly on gelatinized starch, converting it first into products intermediate between starch and sugar ("dextrins" and "maltodextrins") and finally into a particular kind of sugar called "maltose." Starch itself is not directly fermentable to alcohol; maltose is converted into dextrose which is directly fermentable.

The reason for adding the malt is now clear. It supplies the diastase.

The object of heating the mash to 68° C. at the close of the mashing process is to destroy deleterious bacteria. If this were not done, these micro-organisms would develop during the subsequent fermentation, using up a part of the maltose to sustain their growth, and to this extent diminishing the yield of alcohol. On the other hand, a higher temperature than 68° C. would weaken or destroy the activity of the diastase, and this is not desirable. Although the starch may have all disappeared, there still remains some of the intermediate maltodextrins; and if the diastase is not destroyed it can continue its action on these, transforming them into fermentable maltose; whereas in the absence of diastase they are simply so much loss.

Fermentation. The saccharified mash or wort is now, therefore, essentially a solution of maltose, with small amounts of residual dextrins, nitrogenous matters, etc., and some active diastase. When it has been cooled down to about 20° C. (68° F.) it is mixed with yeast ("pitched") to start the fermentation.

The yeast is usually prepared in a separate small mash or "bub." First, however, this mash is often "soured" by inoculating it with a culture of lactic acid bacilli, and allowing them to grow until they have produced a certain amount of lactic acid. Here we must digress for a moment to explain the reason for this.

It is found advantageous to have a small degree of acidity in the wort or "wash" during fermentation as the acid both tends to prevent the development of undesirable bacteria and favours the growth of the yeast. The necessary acid is sometimes added directly, as so much sulphuric acid, or commercial lactic acid, or hydrofluoric acid. In other cases lactic acid is produced in the "bub," as just mentioned, by allowing the pure bacilli to grow in it. When sufficient acid has been

developed, the bub is heated for half an hour to about 74° C. (165° F.) in order to destroy the bacilli and prevent the production of further acid in the main wort. Then the bub is cooled down to 30° C. (86° F.), a little yeast is added, and the bub is set to ferment. In the course of a few hours a vigorous growth of yeast takes place. A portion is reserved for making the next bub, and the remainder added to the main wort.

Fermentation soon commences, as is seen by bubbles of gas (carbonic acid) being evolved, and the appearance of a froth, due to the growth of the yeast. This growth takes place best at a temperature of about 17°-21° C. (63°-70° F.), and marks the first stage of the fermentation. Then the temperature rises, and the main fermentation takes place, with much evolution of gas and agitation of the liquid, as the sugar is converted into alcohol and carbon dioxide (carbonic acid). After about two days this stage is finished : the wash becomes gradually quiescent, and after another day or so the operation is complete. (The evolved carbon-dioxide may be collected and condensed by suitable plant, and utilized in the manufacture of mineral waters, for refrigeration, and other commercial purposes.) The temperature of the wash should not rise above 30° C. (86° F.) at any time, and during the third day it is preferably kept at about 26° C. (79° F.). Coils of piping ("attemperators") through which cold water circulates are used, if necessary, to reduce the temperature during the second or main stage of the fermentation. The fermented wash contains about 12 per cent of alcohol at the end of the operation when a "thick" mash is used, or from 4½ to 7½ per cent when the mash is less concentrated, as is usual in this country.

Theory of the Fermentation Process. Yeast, as already noted in the introductory chapter, is a living

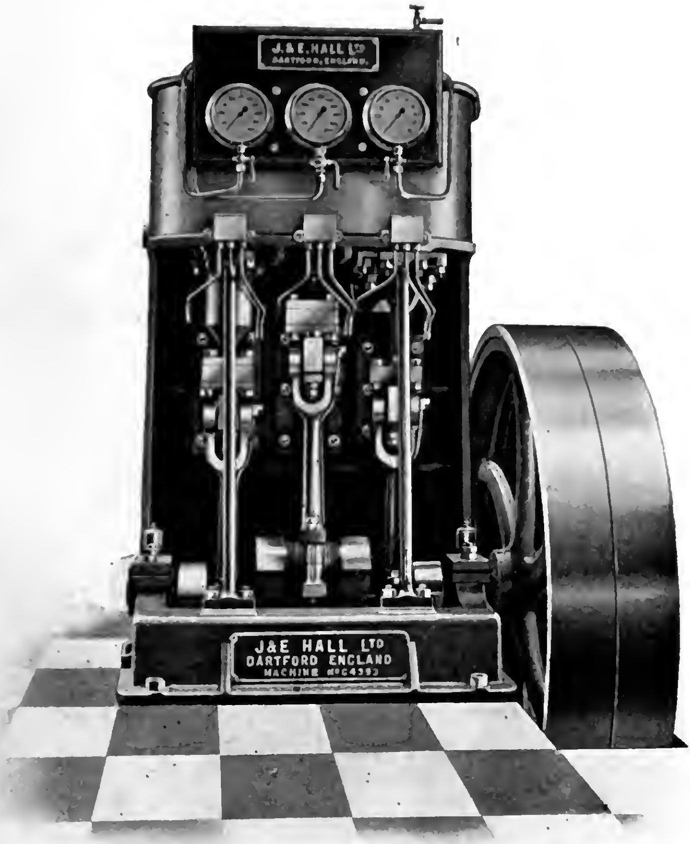


FIG. 2

PLANT FOR COLLECTING CARBON-DIOXIDE FROM FERMENTATIONS

Three-stage Compressor

(vegetable) organism, which, when placed in a suitable medium and under proper conditions of temperature, will grow and reproduce itself. During growth the yeast cells secrete various " enzymes." We have already seen that in malt there is present an enzyme, diastase, which has the power of transforming starch into sugar (maltose). The enzymes of yeast have properties different from those of diastase, and can carry the transformation process further.

One of these yeast-enzymes, *maltase*, attacks the maltose, and converts it into the simpler sugar dextrose. Then a second enzyme, *zymase*, attacks the dextrose, and decomposes it into alcohol and carbon dioxide gas. The latter escapes into the air (or is sometimes collected and utilized), the alcohol remains in the fermented wash.

Alcohol and carbon-dioxide, then, are the main products of the alcoholic fermentation of sugar by yeast. They are not, however, the only products. Small quantities of other substances are produced simultaneously, the principal being glycerin, fusel oil, and succinic acid, with still smaller proportions of other acids and by-products.

It may be mentioned that, by modifying the conditions of fermentation, a relatively large proportion of glycerin can be obtained—of course at the expense of the alcohol yield. It was by this means that Germany, during the last two years of the war, obtained the glycerin necessary for the making of explosives. On adding sodium sulphite to the wort, under proper conditions, it was found that glycerin equivalent to about 20 per cent of the weight of the sugar could be obtained.

Sugar Worts. Where the material employed is not starch, but sugar substances such as molasses, beet juice, or raw sugar itself, there is of course no necessity for the mashing process used in the case of potatoes and

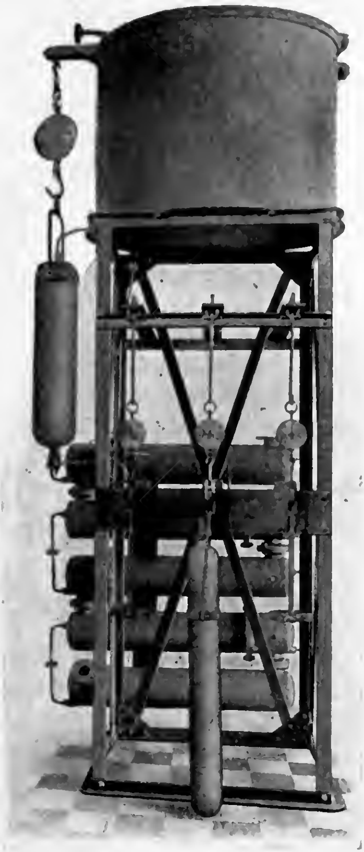


FIG. 3

PLANT FOR COLLECTING CARBON-DIOXIDE FROM FERMENTATIONS

Condenser, Purifying and Bottling Apparatus

grain. The sugar materials are simply dissolved in water to form a wort of the proper specific gravity (1·030–1·040), and may then, if desired, be fermented. It is a common practice, however, with molasses to add a little acid to the diluted material, and boil the latter for a short time in order to "sterilize" it by destroying injurious bacteria. As already mentioned, a slight acidity in the wash is advantageous during fermentation.

Another point may also be noted here. The particular form of sugar, namely, sucrose, which is present in both cane sugar molasses and beet sugar molasses, is, like the maltose produced from starch, not directly fermentable to alcohol. Before this transformation can take place the sucrose must be resolved into two simpler sugars, termed dextrose and laevulose. This is effected by a third enzyme, *invertase*, present in yeast. It can also, however, be brought about by boiling the molasses or sugar juice with a mineral acid (sulphuric or hydrochloric acid) ; and this is sometimes done as a preliminary operation before adding the yeast. After boiling the acidified molasses for an hour, the acid is nearly neutralized with lime or soda, and the liquid cooled down to the proper temperature for fermentation.

The mixture of dextrose and laevulose produced by this treatment of sucrose is termed "invert sugar." It is so called because its action on polarized light is in the inverse sense to that exerted by the original sucrose. Polarized light, we may remark in passing, is much used in the analysis of sugar by means of a specially-devised instrument, the "polarimeter" or "saccharimeter."

"Amylo" Fermentation. Before leaving the subject of fermentation, we must note briefly that malt is not the only substance which can transform starch into

sugar, nor yeast the only agent capable of converting sugar into alcohol. Certain moulds or "mucors" can secrete the necessary enzymes, viz., diastase, maltase, and zymase, and hence can effect both the saccharification of starch and the further conversion of the products into alcohol. A sterilized mash is inoculated with a culture of the mould, which grows very rapidly at the proper temperature—35°–38° C. (95°–100° F.)—and effects the conversion of starch into alcohol at one operation, without the use of either malt or yeast. The fermentation stage, however, is rather a slow one; and hence in practice a small quantity of a special yeast is added when the saccharification stage is well under way, in order to hasten the operation. This process is employed on a large scale in some continental districts.

Distillation. The fermented wash, whether obtained from starch materials or from sugar products, is now ready for distilling. The object of this process is to separate the alcohol from the water and non-volatile substances, such as fragments of husk, glycerin, yeast, protein matters, and mineral salts. The general principle of simple distillation has already been explained in the introductory chapter.

In this country the "Coffey" or "patent" still is largely used, and on the Continent stills of essentially similar type, which produce strong alcohol (94–96 per cent) from the wash in one continuous operation. That is, the wash enters at one end of the still, and from the other end a continuous stream of strong spirit issues. Modern alcohol stills, indeed, are marvels of ingenious and effective devices to obviate the necessity of redistillation. We can do no more here than explain, as simply as may be, the general principle of these devices, taking Coffey's still as example.

This still consists essentially of two columns of perforated copper plates, fixed horizontally one over another so as to form a series of chambers, enclosed at the sides by wooden walls. One column is called the "analyser," the other is the " rectifier." In the analyser the alcohol is freed from the solid matters of the wash and from much of the water ; in the rectifier the remainder of the water, or most of it, is eliminated, leaving nearly pure alcohol to pass out as the finished product.

The wash enters at the topmost plate of the analyser, spreads over the plate to form a thin layer, and passes through a short tube into the chamber below, where it spreads over the next plate, passes through in the same manner, and so on to the lowest chamber. Meanwhile, a current of steam is being blown upwards through the chambers. The steam, bubbling through the perforations in the plates, heats the descending wash, and carries off the alcohol vapour as it rises. The same thing happens at the next plate ; and thus by the time the wash reaches the lowest plate it has been deprived of all its alcohol ; whilst the uprising steam becomes richer and richer in alcohol-vapour. When it reaches the top, this mixture of steam and alcohol passes out of the analyser, and is led by a pipe into the bottom of the rectifier.

Through the rectifier, from top to bottom, there passes a zig-zag tube containing cold wash on its way from the wash-backs to the analyser. This serves as a kind of condenser, keeping the chambers of the rectifier more or less cool. The mixed steam and alcohol-vapour passes upward from one cool chamber to the next, and in each chamber more and more of the steam is condensed, while the alcohol, having a lower boiling-point than the water, is less easily condensed, and becomes more and more free from water as it nears

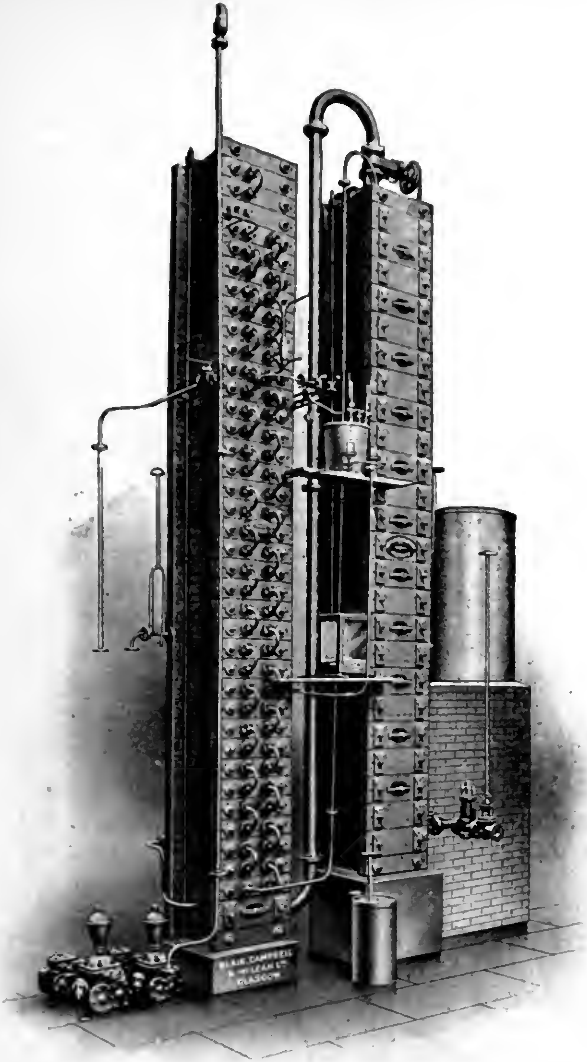


FIG. 4

"COFFEY'S" PATENT CONTINUOUS-WORKING STEAM STILL

the top. Finally, it condenses as strong alcohol on an unperforated "spirit plate," and passes out to the "spirit receiver."

Fusel Oil. It is not, however, only water that is separated from the alcohol in the "rectifier" column. Various impurities, chiefly fusel oil, having a higher boiling point than that of alcohol, are also condensed in the lower chambers, and collect in the bottom of the column. These are termed "hot feints." They are at first passed again into the analyser to recover the small quantity of alcohol still mixed with them; but towards the end of the distillation the quantity of oil increases, and the mixture is collected as "feints" in a separate receiver, where the fusel oil separates and is skimmed off. After purification by washing and redistilling, the fusel oil is employed for making amyl acetate (used as a flavouring essence), and in the manufacture of celluloid varnishes, "dope," and leather substitutes. (*See* Chapter VIII.)

Rectification. The alcohol which is finally collected in the spirit receiver of a "patent" still, such as that described, is usually a nearly pure product. It retains about 4–6 per cent of water, and only very small quantities—often mere traces—of other impurities. Without any further purification it is used for by far the greater number of manufacturing requirements. Sometimes, however, it is required to be of special purity, as for the making of delicate perfumes. Sometimes, again, especially on the Continent, where there are numerous small distilleries run as adjuncts to farms and fruit-growing, the type of still employed is less effective, and produces a much cruder spirit than that obtained in the large distilleries. In such cases the alcohol is further purified by special "rectification." About an equal volume of water is added to the spirit, and the

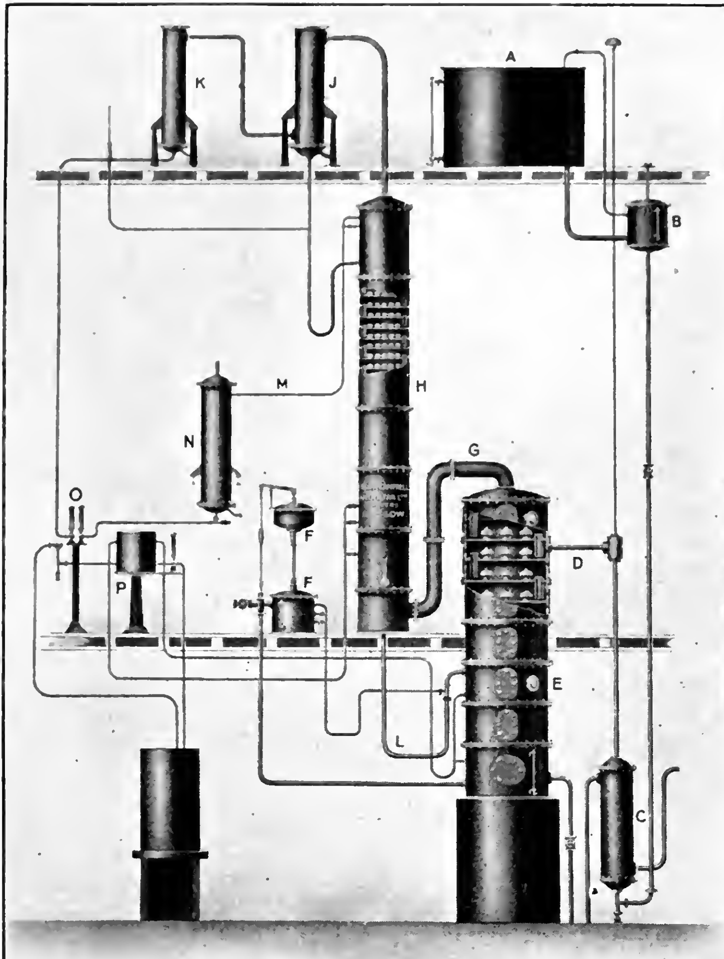


FIG. 5

DOUBLE-COLUMN CONTINUOUS STILL

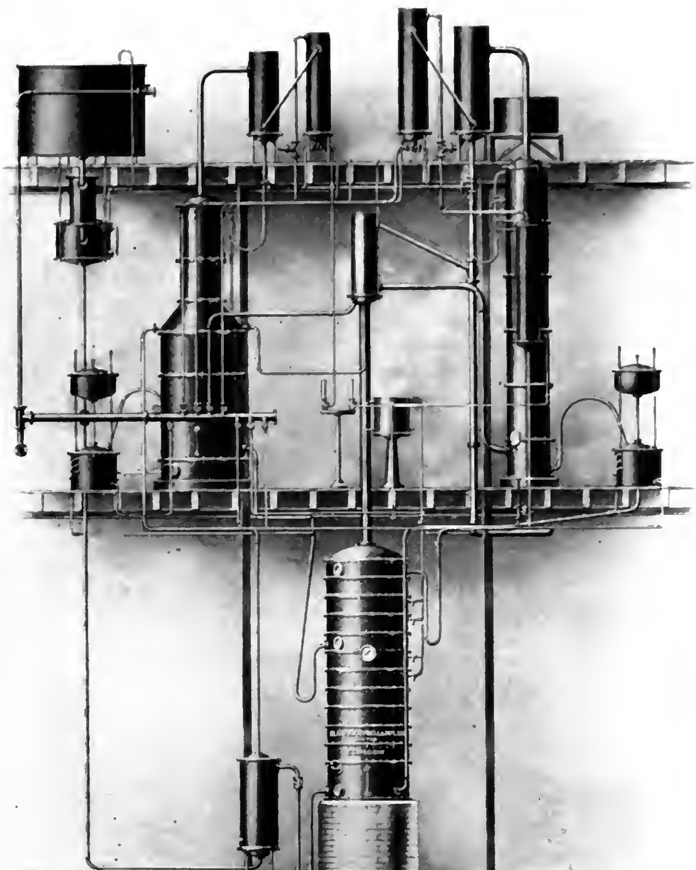
For Producing Spirit 95 to 97 per cent Strength in One Operation

mixture is redistilled. Some of the impurities pass over in the first part of the distillate ("foreshots"), others in the last part ("tailings"), the purified alcohol forming the middle fraction. These fractions are collected separately by some rectifiers; others use a type of still which delivers the pure alcohol continuously, separating the impurities and passing them into other receivers simultaneously. Filtration of the diluted alcohol through charcoal, with subsequent distillation, is also used as a means of obtaining a pure spirit from a cruder form.

Yield of Alcohol from various Materials. Theoretically, pure starch would yield 56·8 per cent of alcohol, and pure cane sugar (sucrose) 53·8 per cent, by weight. In practice, however, various small losses occur, so that the full yield is never obtained. The actual yield from starchy materials, for instance, may be taken as approximately 50 per cent of the starch they contain, instead of 56·8 per cent. That is about 50 lb. of alcohol will, under good working conditions, be produced from every 100 lb. of actual starch present in the raw materials mashed. These raw materials themselves naturally vary rather widely in the amount of starch (or sugar) they contain; but the following table shows the average yields obtained in large distilleries on the Continent—

TABLE II (A). YIELD OF ALCOHOL

Material.	*Alcohol obtained. Gallons per ton.*
Barley	72
Maize	79
Molasses, beet	64
,, cane	76
Oats	65
Potatoes	26
Rice	85
Rye	75
Sugar beets	11 to 24



By permission of *Blair, Campbell & McLean*

Fig. 6

TRIPLE-COLUMN CONTINUOUS STILL

For Producing nearly Pure Spirit 95 to 97 per cent Strength in One Operation

A more extended list, including various fruits and tropical products, has been compiled by a writer in the *Scientific Australian* (1918; p. 968). In this case the yield is expressed in gallons of 95 per cent alcohol—i.e. approximately the strength at which the spirit is actually distilled—

TABLE II (B). YIELD OF ALCOHOL

Material.	*Gallons of Alcohol* (95%) *per ton.*
Sugar molasses	65
Sorghum stalks	12½
Wheat	83
Barley	70
Maize	85
Sorghum grains	87
Potatoes	20
Sweet potatoes	35
Sugar beet	18
Artichokes	22
Cassava	39
Apples and pears	12
Apricots and peaches	11
Grapes	18
Bananas	13
Water melons	3
Zamia palm (*Macrozamia*)	18
Grass tree (*Xanthorrhoea*)	12
Sawdust (soft woods)	20

CHAPTER III

ALCOHOL FROM CELLULOSE SUBSTANCES: SYNTHETIC ALCOHOL

FERMENTABLE sugars can be obtained not only from starch, but from more unlikely-looking materials such as waste wood and straw. It is also possible to produce alcohol without employing fermentation at all: by building it up, as it were, from simpler substances. Although no very considerable quantities are at present made by these methods, they are important processes, inasmuch as the raw materials are not foodstuffs, but waste products or cheap non-edible substances. Hence whatever amounts of alcohol are produced from these sources, whether large or small, help to conserve the starch and sugar products available for use as food.

CELLULOSE MATERIALS

Wood Waste. Wood contains about 50 per cent of cellulose substances, and a part of these can be converted into fermentable sugars by treatment with acids under pressure.

Sawdust or other wood waste is placed in a large rotating cylinder or globe, and sulphur dioxide gas passed in. Then steam is introduced until a pressure of 100 lb. is reached, and the temperature brought up to 135°–163° C. (275°–325° F.). The container is rotated slowly during about three-quarters of an hour, to allow of the sulphurous acid obtaining free access to the wood. Under these conditions the acid attacks the cellulose constituents, partly decomposing them,

and transforming a portion into fermentable sugar-like bodies.

When this process is completed, the excess of sulphur dioxide is blown off, and the woody residue extracted with water to dissolve out the resulting sugar substances. The solution thus obtained is neutralized with lime, fermented with yeast, and distilled to separate the alcohol. About 16–21 gallons of alcohol are obtained per ton of dry wood treated.

This process has been operated for several years in the United States, though on no very large scale. At present there are said to be two plants in operation, one at Georgetown, South Carolina, and the other at Fullerton, Louisiana ; their output some time ago was about 2,000–3,000 gallons of alcohol per day in each case. Probably it may be said that the process is successful where the conditions are favourable for obtaining good, cheap, and constant supplies of the raw material. Such places, however, are relatively few, and sawdust is a bulky article to transport, so that its collection from outlying areas is inconvenient and costly. Hence no very considerable production of alcohol from sawdust has hitherto been effected.

Sulphite-pulp Liquor. In countries where wood pulp is made by treating wood with sulphites, very large quantities of waste liquor are produced. This liquor contains a small amount of fermentable sugars, about 2 per cent or less, arising from the action of the sulphite on the cellulose of the wood. Methods have been found for profitably recovering these sugars from the liquors and converting them into alcohol.

The free sulphurous acid contained in the liquor is partly expelled by evaporation, and the remainder neutralized with lime and chalk. After cooling the neutralized liquor to the proper temperature, a yeast

food such as malt extract or milk whey is added, together with yeast, and the liquor is set to ferment. When the fermentation is complete, the alcohol is separated by distillation as usual.

This is a very noteworthy instance of the utilization of a waste product. True, the quantity of alcohol obtained from this source is small compared with the total world production, but it is substantial in the few localities where it can be carried on. About a million gallons a year are recovered from waste sulphite liquor in Sweden, and there are factories in Norway, Switzerland, Germany, and America.

Rice Straw. An interesting attempt is now being made to obtain alcohol commercially from rice straw and husk. This is a cheap material, available in large quantities in tropical countries.

The straw is softened by steaming, and treated with hydrochloric acid, or with bleaching powder and chlorine, in order to disintegrate the fibres. The softened mass is then pulped, and the hydrolysis of the cellulose completed by heating with diluted hydrochloric acid under pressure. After the conversion to sugar is finished, the acid is neutralized, and the solution of sugars fermented and distilled.

It is understood that large-scale experimental trials of this process are to be made in India, to see whether the production of alcohol from these and similar cheap cellulose materials can be definitely established. Success would open out the prospect of utilizing a large amount of waste cellulose substances as sources of alcohol.[1]

[1] Mr. Henry Ford, of car and " tractor " fame, has recently been quoted as saying : " I am now making the best fuel my tractors can use out of straw. I am putting up a 35,000 dollar plant now to manufacture alcohol from straw alone ; just to show people that it can be done." (*Oil and Gas Journal*, 1920, xviii, 36.)

Synthetic Alcohol

(1) **From Calcium Carbide.** No doubt many readers are aware that acetylene gas, often used as a source of light, is obtained by the action of water on calcium carbide. The water decomposes the carbide, giving off a stream of acetylene, which can then be burned in lamps, or utilized for other purposes. It may, for instance, by appropriate chemical treatment be converted into a liquid substance termed aldehyde (acetaldehyde). This aldehyde is closely related to alcohol ; it can readily be produced from alcohol ; and conversely it can, though less easily, be transformed into alcohol.

The difference in the chemical composition of the two substances consists in the fact that alcohol contains more hydrogen than does aldehyde. Now it is found that if the vapour of aldehyde is mixed with hydrogen, and the mixture passed over nickel powder at a temperature of 140° C. (284° F.), the aldehyde combines with the hydrogen, and is thus converted into alcohol.

This process was worked for some time during the period of the war ; but little has been heard of it since, and probably it is not a remunerative manufacture in normal circumstances. The raw materials for making the calcium carbide are coke and limestone ; but the carbide can only be produced cheaply where an economical source of electricity, such as water power, is available to work the electric furnaces used. Nevertheless it is a notable and interesting fact that alcohol can be obtained in quantity from substances like coal and limestone as the main raw materials.

(2) **From Coke Oven Gas.** This gas, emitted as a by-product from ovens in which coal is coked, consists mainly of hydrogen (50 per cent), and methane or marsh gas (25 per cent), with smaller quantities of nitrogen, water vapour, and tarry impurities. Among

its minor constituents is a very small proportion—about 2 per cent—of ethylene gas. It is, apparently, so insignificant a constituent that one might almost wonder how it could even be detected in such a mixture, let alone separated and utilized. Yet it can be converted into alcohol ; and if all the ethylene produced from the coal carbonized in British coke ovens (about 15 million tons *per annum*) were thus converted, it is calculated that the yearly supply of alcohol from this source would be no less than 24 million gallons.

Here let us digress for a moment to recall an episode in the history of chemistry. Faraday, about a century ago, was experimenting with ethylene, and found that this gas could be absorbed by strong sulphuric acid. He gave a specimen of acid, which had taken up eighty times its own volume of ethylene, to Hennell, another chemist of that period. Some years afterwards, Hennell recorded the fact that in the mixture given him by Faraday he had identified another acid (ethyl sulphuric acid), and that, on adding water to this and distilling it, alcohol was produced (1828). This observation it is which, after remaining, as it were, a mere laboratory curiosity for nearly a hundred years, has now been made the basis of a process for manufacturing alcohol from an apparently worthless by-product. It is one of many illustrations which might be cited, showing how a purely scientific research, carried out in pursuit of knowledge and with no motive of ulterior profit, may lead to results of considerable value to the community at large.

The coke-oven gas is first purified to eliminate tarry matters—ammonia, naphthalene, benzene hydrocarbons, and hydrogen sulphide. Olefine hydrocarbons other than ethylene are next removed by passing the gas through a tower containing rather weak sulphuric acid (80 per

cent) at the ordinary temperature. Then the gas is heated to a temperature between 60° and 80° C. (140°–176° F.), and passed through another tower containing strong sulphuric acid (95 per cent) heated to the same temperature. It is here that the ethylene is taken out. About seven-tenths of it is absorbed by the warm, strong acid in 2½ minutes. The acid can be used until it has absorbed up to 5 per cent of its weight of ethylene.

From the absorption tower this acid, now containing the ethylene in the form of ethyl hydrogen sulphate (Hennell's "ethyl sulphuric acid"), is led to a special form of distilling column, where it meets with a current of steam. This dilutes the acid, and decomposes the ethyl hydrogen sulphate into alcohol and sulphuric acid. The heat produced during the dilution is sufficient to raise the temperature of the diluted acid to 90°–100° C. (194–212° F.). Under these conditions the alcohol distils over, is subsequently condensed, and finally leaves the plant as 95 per cent alcohol.

The diluted acid is concentrated by heating, and used over again for the absorption of more ethylene.

This process has passed beyond the purely experimental stage, but at the time of writing has not developed into manufacture on a large scale. It appears, however, to be the most promising of the "synthetic" methods, and there is no doubt whatever that alcohol can be produced in quantity by the process. The commercial prospects depend, of course, upon the cost of production relatively to the value of the alcohol produced. If the method can establish itself permanently, it will be of considerable technical importance. There is no likelihood that the full theoretical quantity, 24,000,000 gallons yearly, corresponding with the coal carbonized in Great Britain, will ever be obtained, because—to mention only one obstacle—there are many small

coke-oven plants where it would probably not pay to install a recovery apparatus. But even if only one-half of the total quantity should eventually be obtained, it will be a very substantial addition to our resources, since our present annual production of alcohol is only about 26,000,000 gallons for all purposes.

CHAPTER IV

VARIETIES AND PROPERTIES OF ALCOHOL

ALCOHOL comes into commerce under various forms, as, for example, "absolute" alcohol, rectified spirit, spirit of wine, methylated spirit, and so on. The present chapter is devoted to a description of these different varieties.

Absolute Alcohol. Even the most effective stills do not yield alcohol entirely free from water. To remove the last four or five per cent of water recourse must be had to chemical treatment. For this purpose some substance is chosen which, having a marked affinity for water, will retain the latter, and thus "dehydrate" the alcohol when mixed with it.

Quicklime is the dehydrating agent generally employed. Spirit of about 94 to 96 per cent strength is produced directly by the large continuous stills mentioned in Chapter II, and some of this spirit is taken as the starting point. It is digested with about one-fourth to one-third of its weight of quicklime in a steam-jacketed vessel provided with a stirring apparatus to keep the lime and alcohol well mixed. The alcohol is then distilled off, the vapours, before condensation, being passed through a vessel containing more lime. As the first and last portions of the distillate are prone to be rather weaker than the middle portion, they may be reserved for re-treatment in a later operation. The middle fraction is very nearly free from water, and may be sold as the commercial "absolute" alcohol; but if the chemically pure alcohol is required, a second or a third treatment with lime may be necessary.

For small operations, if strong alcohol is not at hand to start with, it may readily be obtained by adding a good proportion of dry (recently heated) potassium carbonate to weaker spirit, and distilling off the upper layer of alcohol which forms in the mixture.

Chemically pure alcohol, entirely free from water, is very difficult to prepare, and is only employed in scientific researches. It boils at 78·3° C. (172·9° F.) under a barometric pressure of 760 millimetres; and has the specific gravity 0·79359 at 15·6° C. (60° F.), compared with water at the same temperature. It is a mobile, colourless liquid, with a spirituous odour and a pungent taste. When ignited, it burns with a pale blue flame, smokeless and non-luminous. It mixes with water in all proportions.

As met with in commerce, "absolute" alcohol usually contains from 0·5 to 1·5 per cent of water. The British Pharmacopoeia requires it to contain not more than 1 per cent of water by weight, and to have a specific gravity from 0·7940 to 0·7969. To ensure that the alcohol does not contain an excessive quantity of water it must conform to the following test: "Anhydrous copper sulphate shaken occasionally during two or three hours with about fifty times its weight of absolute alcohol does not assume a decidedly blue colour."

Plain Spirit, or Plain British Spirit. This is the alcohol as ordinarily sent out by the distilleries, "plain," because no flavourings or colourings are added to it. The strength is usually between 94 and 96 per cent by volume, and specific gravity 0·8197–0·8119. It is the spirit usually received, for example, by manufacturing chemists, to be used in the making of tinctures and other spirituous medicines; by essence and perfume makers for the compounding of flavouring essences and of perfumes; and by methylators for conversion into

methylated spirit, which is employed in varnish making, as a solvent for dyes, in the production of transparent soaps, and in numerous other industries. (*See* Chapter V.)

Rectified Spirit: Spiritus Vini Rectificatus, or "S.V.R." By "rectified spirit" is generally understood in this country the "Alcohol, 90 per cent" of the Pharmacopoeia. It is plain spirit (*see* above) reduced by addition of water to the uniform strength of 90 per cent by volume for use in pharmacy; it is, in fact, the pharmacist's standard alcohol, from which he prepares various spirituous medicines and the four official "diluted alcohols." The specific gravity of rectified spirit is 0·8337, and it contains, by *weight*, 85·68 per cent of absolute alcohol, and 14·32 per cent of water.

In a more general sense, "rectified spirit" includes any alcohol which has undergone the process of rectification (*see* Chapter II) to render it suitable for some special purpose, such as the making of delicate perfumes or particular beverages.

Diluted Alcohols. For use in compounding medicines there are four official "diluted alcohols" described in the Pharmacopoeia. They contain respectively 70, 60, 45, and 20 per cent of absolute alcohol by volume and are obtained by diluting the 90 per cent alcohol with water as shown in the accompanying table, which gives also the respective specific gravities.

Alcohol required.	Specific gravity.	(1) Volume of water to be *mixed with* 1 litre of 90 per cent alcohol.	(2) Volume of 90 per cent alcohol to be *diluted to* 1 litre at 15·6° C. (60° F.).
		Cubic centimetres.	*Cubic centimetres.*
70 per cent .	0·8899	310·5	777·8
60 ,, .	0·9134	536·5	666·7
45 ,, .	0·9435	1053·4	500·0
20 ,, .	0·9760	3558·0	222·2

Either method (1) or method (2) can be used, as may be the more convenient.

In connection with the dilution of alcohol it may be mentioned that a contraction of volume occurs when water and alcohol are mixed, so that the volume of the mixture is less than the sum of the original volumes of water and alcohol taken separately. The amount of contraction depends upon the relative proportions of the two liquids. It is a maximum when 52 volumes of alcohol are mixed with 48 of water. The sum of these separate volumes is 100, but the volume of the mixture, if measured at the same temperature, is less than 100. If the temperature chosen is 20° C. (68° F.), the resulting volume, in fact, is only 96·3.

This phenomenon of contraction is of considerable importance in connection with calculations of alcoholic strengths. Take, for instance, the preparation of 45 per cent alcohol as shown in the foregoing table, method (1). We have to add 1053·4 cubic centimetres of water to 1 litre (1,000 cu. cm.) of 90 per cent alcohol. But if there were no contraction the quantity of water would have been only 1,000 cu. cm., that is, an equal volume, since the required strength, 45, is exactly one-half of the original strength of the alcohol, 90 per cent. To halve the strength we require to double the volume, but on account of the contraction we do *not* double the volume of the alcohol by adding an equal volume of water to it. More than an equal volume is required, namely, 1053·4 cu. cm. instead of 1,000 cu. cm.

Spirit of Wine. This, legally, means rectified spirit of a strength not less than 43° above "proof" (see below) which corresponds with 81·6 per cent of alcohol by volume. The term is often used as synonymous with rectified spirit, or more generally, with "plain" spirit of indefinite strength not lower than 43° over proof.

Proof Spirit. For fiscal purposes, and in commercial transactions where duty-paid alcohol is concerned, and where, consequently, the amount of duty largely determines the price, "proof spirit" is the standard alcohol. The duty is levied on spirituous beverages, etc., according to their equivalent in proof spirit. One legal definition of proof spirit is "that which at the temperature of 51° F. weighs exactly $\frac{12}{13}$th parts of an equal measure of distilled water." Proof spirit, therefore, is alcohol of a particular strength. It contains, in fact, 49·28 per cent of alcohol by weight, and 50·72 per cent of water, and its specific gravity is 0·91976 at 60° F. (15·56° C.), water at the same temperature being taken as unity. The proportion of alcohol *by volume* in proof spirit is 57·1 per cent. For rough purposes, it is convenient to remember that proof spirit contains nearly one-half its weight of alcohol, and rather more than one-half of water.

The foregoing applies to proof spirit values as employed in the United Kingdom. Different countries, however, use different values. Thus the United States proof spirit contains 50 per cent of alcohol by volume.

"Over proof" and "under proof" are expressions commonly used in trade and fiscal practice. A particular spirit is said to be, for example, 60 "o.p." (over proof); another, is, say, 30 "u.p." (under proof). Let us see what these expressions mean.

Proof spirit being taken as 100 per cent, or 100°, then 1° represents 1 per cent of proof spirit; 60° over proof, therefore, denotes $60 + 100 = 160°$, or 160 per cent of proof spirit. Alcohol of 60 o.p. strength is thus 60 per cent stronger than proof spirit; 100 volumes of it contain as much real (absolute) alcohol as do 160 volumes of proof spirit.

Similarly, alcohol of strength 30 u.p. is 30 per cent

weaker than proof; 100 volumes of it contain 100 – 30 = 70 per cent of proof spirit.

Absolute alcohol is of strength 75·35 over proof. That is, 100 volumes of absolute alcohol are equivalent to 175·35 volumes of proof spirit.

Methylated Spirit. The various forms of this are described in Chapter V (Industrial Alcohol).

Immature Spirit. An Act of Parliament passed in 1915 provides that, with certain exceptions, "no British or foreign spirits shall be delivered for home consumption unless they have been warehoused for at least three years." Alcohol which has not been kept in warehouse for this statutory period is known as "immature spirit."

The object of this restriction upon delivery is to ensure that spirit used for beverages such as whisky shall be "matured" or mellowed by storage. Hence the restriction is not to apply to duty-*free* spirit, which is not used for beverages but for industrial and scientific purposes. Neither does it apply to spirits delivered to rectifiers, manufacturing chemists, makers of perfumes, or other duly licensed persons, subject to the payment of any duty that may be imposed. Nor, again, is the section of the Act in question to interfere with the supply of rectified spirits of wine, for the purpose of making medicines, to registered medical practitioners, to hospitals, and to persons or firms entitled to carry on the business of a chemist and druggist.

As regards duty-paid immature spirit used for making medicines and for scientific purposes, rebate of the greater part of the duty may be obtained. The medicines, however, must be articles "recognized" by the Commissioners of Customs and Excise as articles used for medical purposes. There are certain spirituous preparations, such as tincture of orange, spirit of

cinnamon, and spirit of peppermint, which are used as flavourings for beverages or as constituents of perfumes, and these are not admitted to rebate, although they are frequently employed in medicines.

The importance of this provision for obtaining rebate of duty on alcohol used in making medicines will readily be seen when it is mentioned that, at the time of writing (1920), the excise duty on immature spirit is 74s. per proof gallon, equivalent to 116s. 9d. per bulk gallon of 90 per cent alcohol (approximately 58 over proof). Of this amount, all but 14s. 9d. per proof gallon, or 23s. 3d. per bulk gallon at 58 o.p., is recoverable as rebate. That is, the duty on alcohol used for making approved medicinal articles (or for scientific purposes) is at the present time, after allowing for the rebate, almost exactly one-fifth of that charged on the alcohol employed as a beverage.

For obtaining rebate, proper accounts of the spirit must be kept, showing the date, bulk quantity, strength, and proof quantity of each consignment of spirit received, and the details of use. The following factors for converting alcohol of various strengths into proof gallons will be found useful in this connection—

(1) LITRES TO PROOF GALLONS

Alcohol.	*Multiply no. of litres by*
90 per cent (vol.)	0·3471
70 ,, ,,	0·2697
60 ,, ,,	0·2312
45 ,, ,,	0·1733
20 ,, ,,	0·0767

(2) BULK GALLONS TO PROOF GALLONS

Alcohol.	*Multiply no. of bulk gallons by*
90 per cent (vol.)	1·5779
70 ,, ,,	1·2263
60 ,, ,,	1·0510
45 ,, ,,	0·7877
20 ,, ,,	0·3487

(3) FLUID OUNCES TO PROOF GALLONS

Alcohol.	*Multiply no. of fluid ozs. by*
90 per cent (vol.)	0·00986
70 ,, ,,	0·00766
60 ,, ,,	0·00656
45 ,, ,,	0·00492
20 ,, ,,	0·00218

"Enumerated" Spirits. This is a tariff term. The Customs authorities classify brandy, rum, imitation rum, and geneva as "enumerated spirits"; whilst all other imported spirits are classified as "unenumerated."

"Compounded Spirits" are spirits which have been sweetened or flavoured, or both. The term is a general one, and includes such articles as British brandy, gin, sloe gin, imitation rum, liqueurs, and cordials; but it is not confined to beverages.

Spirits used as Beverages. The chief of these are brandy, gin, rum, and whisky. They differ from "plain" spirit by containing ingredients which impart special flavours to them. These ingredients are either added directly, as with gin, or are produced during the fermentation of the special materials employed, and not completely eliminated during the subsequent distillation of the spirits.

Brandy is distilled from fermented grape juice. The distillation is so arranged that the spirit is not completely rectified from the fusel oil and other secondary products (esters, aldehydes, acids, etc.), and it is these secondary constituents, especially the "esters," which confer upon brandy its characteristic flavour. As distilled, brandy is colourless, but before being sent into consumption it is coloured, either by direct addition of caramel colourings, or by extraction of colouring matter from the storage casks.

"British brandy" is not prepared from wine-spirit, but

by adding flavouring ingredients to plain spirit made from grain, or from other non-vinous materials.

Gin is, typically, a grain spirit which has been rectified, and then flavoured by distillation with juniper-berries. Other aromatic flavourings are often employed in addition to the juniper ingredient ; the chief of these are angelica, almonds, calamus, cardamoms, cassia, coriander, fennel, grains of paradise, liquorice, and orris. Sometimes the flavouring materials are distilled separately from the main bulk of the alcohol, with a small quantity of spirit, and the product is mixed subsequently with the remainder of the rectified spirit. Sometimes, too, the product sold as gin is made by merely mixing various essential oils with ordinary plain or patent-still spirit. Gin may be either "sweetened" or "unsweetened." The sweetened varieties contain usually from 2 to 4 per cent of sugar, or occasionally, as much as 6 per cent.

Rum is a potable spirit distilled from fermented cane sugar molasses and skimmings obtained during the purification of sugar. Jamaica rum is produced by a process of slow fermentation, lasting from ten to twelve days ; Demerara rum by quick fermentation, finished within about two days. In the former case there is bacterial action as well as that due to yeast ; whereas in the quick process the fermentation is due almost solely to yeast.

Like brandy, rum is distilled in stills of simple type ("pot" stills), or else in rectifying stills which stop short of complete rectification. In either case, the whole of the "secondary" products is not eliminated from the spirit, and to the portion that remains is due the characteristic flavour of the rum. But whereas the flavour of brandy is attributed mainly to a product termed "oenanthic ester," that of rum is due to other

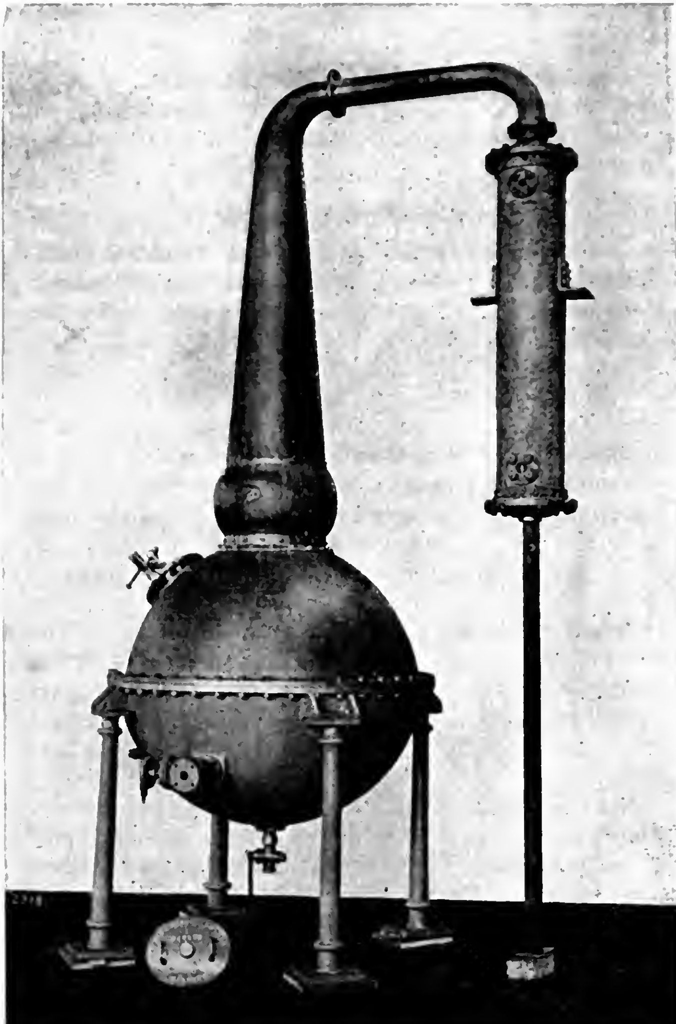


Fig. 7

STEAM JACKETED COPPER GIN STILL

esters, chiefly ethyl butyrate, ethyl formate, and ethyl acetate.

An "artificial" or "imitation" rum is made by flavouring and colouring plain spirit with artificial essences.

Whisky. This spirit is made either from malt, or from a mixed mash of malt and unmalted grain. The grain includes barley, maize, oats, rye, and wheat. Both pot stills and patent stills are employed for the distillation. For Scotch pot-still whisky malt alone is generally used; in Irish pot-still distilleries a mixture of malt and unmalted grain is the rule. The bulk of the whisky as sent into consumption is the blended product of pot-still and patent-still distilleries. The patent-still spirit is of a milder character than that from the pot still, and the mixture appeals to the palate, as well as to the pocket, of the greater number of consumers. Many blends, however, are made of pot-still whiskies alone, as these are not of uniform character, but differ among themselves in respect of flavour and quality. The blending is for the purpose of obtaining a particular character or quality, and of keeping this character as uniform as possible. Purchasers of a special brand of whisky naturally like to find always the same flavour and character in that brand.

Newly-distilled whisky has a crude, harsh flavour, which is softened and mellowed by storing the liquor in casks for a number of years. Sherry casks are often used for this "maturing" process, though the larger proportion of whisky is matured in plain wood. As with brandy and rum, the special flavour of whisky is due to the nature and amount of the secondary products which are allowed to remain in the liquor when the fermented wash is distilled. In Scotland, it is a common practice to use peat in curing the malt used for making

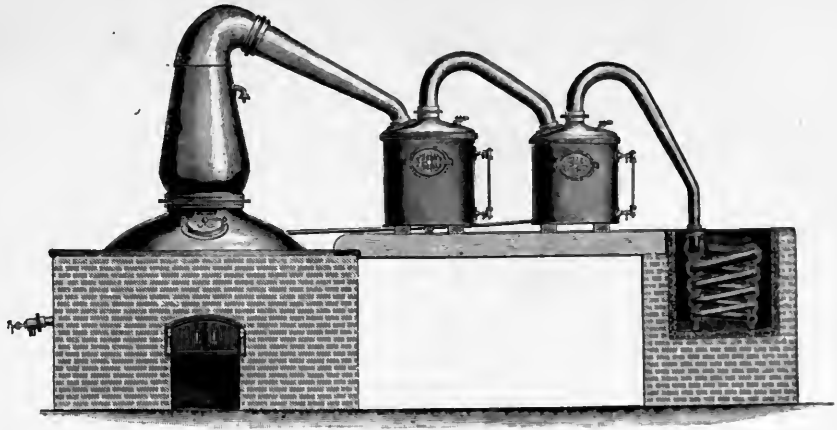


Fig. 8

COPPER RUM STILL

pot-still whiskies, with the result that certain kinds of Scotch whisky possess a marked peaty flavour. For trade purposes Scotch whiskies are classified into (1) Highland malts ; (2) Lowland malts ; (3) Campbeltowns ; (4) Islays ; and (5) Grain whiskies. The last includes the patent-still whiskies. Irish " self " whiskies are usually marketed under the name of the distiller or distillery ; but most of the bottled whiskies are blended products, sold under the name of the blender or under some fanciful description. Rye whisky is an American beverage made with malted rye, or with unmalted rye and a small proportion of barley malt or rye malt. Bourbon whisky is made in Kentucky from maize, rye, and barley malt, the maize forming more than one-half of the total grain.

The colour of whisky is due to extractive matters derived from the storage casks, with sometimes a little added caramel. Newly-distilled whisky is colourless.

CHAPTER V

INDUSTRIAL ALCOHOL

Most countries tax alcohol used as a beverage, partly as a means of obtaining revenue and partly as a check upon the indiscriminate use of spirituous liquors. But, as we have already indicated, alcohol has a great many applications in the arts and manufactures ; and it is obviously desirable to have no unnecessary increase in the cost of the spirit used for these industrial purposes. On the other hand, human nature being what it is, if pure alcohol were allowed in manufactures free of tax and without restrictions there would very soon be a considerable decrease in the revenue obtained from this source, to say nothing of the moral and physical detriment attendant upon increased illicit drinking. Stringent regulations and close supervision would no doubt help to minimize these dangers, but would unduly hamper legitimate operations. Also they would increase the cost of the manufactures ; in effect they would still be a tax, though under another name.

The remedy is fairly obvious. Make the alcohol, if possible, so nasty that it cannot be drunk. Mix with the spirit, if you can, something which will render it unpalatable or even nauseous, but which will not interfere with the industrial operation or purpose for which it is required. Then let the manufacturer have it free of duty, and with a minimum of restrictions.

That is the ideal treatment—properly to " denature " the alcohol, as the phrase goes. But the selection of the ideal " denaturant " is by no means an easy matter. Many substances will make alcohol too nauseous to

drink, but that is not the whole story. They may be too easily got rid of, or they may be too costly, or they may interfere too much with the particular purpose to which the user wishes to put the spirit. In view of the multiplicity and the diverse character of the operations in which alcohol is employed, a very little consideration will show that a denaturant which is unobjectionable in some industries may be quite unsuitable in others. Resin, for example, might be of no detriment in alcohol for varnish making; but a photographer would object strongly to its presence in the spirit with which he dries his plates or prepares his emulsions.

Denaturants. The following are the chief conditions which a good denaturant should fulfil—

(1) It should impart a taste and smell sufficiently disagreeable to prevent the alcohol being drunk, even after dilution, sweetening, or flavouring.

(2) It should not be capable of easy removal by filtration, distillation, or any other process which can readily be applied, or which is ordinarily used in manufacturing operations.

(3) It should be capable of easy and certain detection, even when present in minute quantities only.

(4) It should mix readily with the alcohol, and produce a mixture capable of being used in essentially the same way as the undenatured alcohol in manufacturing processes.

(5) Its cost should not add materially to the price of denatured spirit as compared with that of ordinary alcohol free of tax.

Whilst many substances fulfil one or more of these conditions, no single substance has yet been discovered which satisfactorily fulfils them all. The one which approaches most nearly to a perfect denaturant is crude

methyl alcohol or "wood naphtha" (wood spirit), first introduced for the purpose by the revenue chemists of this country in 1855. It is obtained as one of the products resulting from the dry distillation of wood, and must be carefully distinguished from the ordinary ("ethyl") alcohol produced, as described in Chapter III, by converting the cellulose of wood into fermentable sugars, and fermenting and distilling these.

Other substances in use as partial denaturants include mineral naphtha (a light petroleum oil), crude pyridine (obtained from coal tar), turpentine, coal tar oil, solvent naphtha, acetone oil, bone oil, benzol, petroleum distillates of higher boiling point than mineral naphtha, and aniline oil. These various articles would seem to be nauseous enough, in all conscience: they suggest a veritable witch's cauldron. Nevertheless it is a fact that all of them are lacking in some respects; and large money prizes have from time to time been offered—and offered in vain—for the discovery of more perfect denaturants.

In nearly all countries two chief kinds of denatured alcohol are sanctioned for general and industrial use—

(1) "*Completely-denatured*" spirit, intended for use by the public for burning, cleaning, household, and minor manufacturing purposes.

(2) "*Partly-denatured*" alcohol for industrial operations on a large scale and for use generally where the first variety is unsuitable.

The "completely-denatured" alcohol for general use is commonly mixed with a larger percentage of wood-naphtha than is required in the "partly-denatured" spirit for manufacturing purposes; and it contains, in addition, a small quantity of some other substance, such as mineral oil or pyridine, to intensify its nauseous character. It is also often coloured with an aniline dye.

Methylated Spirit. In this country such alcohol as that just described is known as "*mineralized methylated spirit.*" It contains 90 parts (by volume) of ordinary plain spirit, and 10 parts of wood naphtha, together with three-eighths of one per cent of mineral naphtha, and sufficient dye to give it a violet tint. Practically the same mixture is used in France and in the United States, as well as in Canada and in other British possessions.

Mineralized methylated spirit is the kind which is ordinarily retailed for burning, domestic, and general purposes. It may be obtained in quantities not exceeding 4 gallons at a time from licensed retailers such as oil merchants, grocers, and chemists. This spirit becomes milky on dilution with water, and is so nauseous as to be almost undrinkable, except by persons of depraved taste, even when sweetened and flavoured. Cases of such methylated spirit drinking, however, are by no means unknown, especially in the poorer quarters of our larger towns. It is illegal to purify this or any other kind of methylated spirit, or to prepare it in any way for use as a beverage.

The "partly-denatured" alcohol in general use in this country for industrial purposes is known as "*industrial methylated spirit.*" It contains 95 parts (by volume) of ordinary plain alcohol and 5 parts of wood naphtha. It differs, therefore, from the mineralized spirit in that it contains no mineral naphtha and no aniline dye, and in having one-half the proportion of wood naphtha. Such a mixture is obviously much purer than the mineralized kind. It is not undrinkable when diluted, sweetened, or flavoured; and hence greater precautions have to be taken by the revenue authorities to prevent its illegal use than are necessary in the case of mineralized methylated spirit. It is not allowed to be sold by retail;

a user must be specifically authorized to receive it, and he must obtain it directly from the "methylators" who make the spirit. No smaller quantity than 5 gallons can be supplied. Further, except where the annual quantity required is not more than 50 gallons, the user must give a bond for the proper employment of the spirit, which may only be used for the purposes authorized under the bond. The principal restriction upon the purposes to which the industrial spirit may be put is that it may not be used in beverages or in perfumes or in medicines capable of being taken internally; nor may it be employed as a fuel alcohol, or for heating and lighting. For all ordinary manufacturing operations however, from the making of furniture polish to the dyeing of artificial flowers or the production of an anaesthetic, the receipt of industrial methylated spirit is authorized, and its use allowed under conditions of supervision which are by no means unreasonably irksome.

Specially Denatured Alcohol. For certain industrial operations methylated spirit, whether mineralized or industrial, is not suitable. This may be due to a variety of causes, one of the most frequent, perhaps, being the fact that the methyl alcohol of the wood naphtha may enter into chemical reaction and produce compounds different from the particular product required. In such cases ordinary alcohol may be allowed free of duty, but denatured with some denaturant appropriate to the special operation in question. Frequently this denaturant will be one of the ingredients or chemical reagents used in the manufacture. For example, in making the dyestuff "intermediate" product ethylaniline, the methyl alcohol of wood naphtha, is undesirable as a denaturant, because it gives rise to methylaniline; but aniline oil itself, the main raw

material, is a very nauseous body, and can be used (if so authorized) instead of wood naphtha to denature the alcohol employed. On the other hand a denaturant might be selected which has no necessary connection with the manufacture, but is chosen simply because it renders the alcohol more or less unpotable, and does not seriously interfere with the operations in view.

As an example of this, the following United States specification for a specially-denatured alcohol may be quoted. It is for spirit to be used in making sulpho-methane (sulphonal : a medicinal soporific) :—To every 100 gallons of plain spirit are to be added 1 gallon of pyridine bases and 1 gallon of benzol.

Specially-denatured alcohol differs from methylated spirit in that the denaturing process is carried out on the user's premises, whereas the latter spirit is made in bulk by specially-licensed "methylators," who distribute it ready-made to the prospective user. In general, as the special denaturants are less effective than wood naphtha for preventing possible malpractices, the use of specially-denatured spirit involves more official restrictions and supervision than are required with methylated spirit.

Alcohol not Denatured. It may be mentioned that, for teaching and scientific research, universities and other public institutions are allowed to receive alcohol (free of duty) without the addition of any denaturant.

Also pure *methyl* alcohol, which is liable to spirit duty when purified sufficiently to be regarded as potable, is allowed free of duty, and without denaturing, for the manufacture of certain fine chemicals, in cases where industrial methylated spirit is unsuitable.

Summing up, then, we find that in the United Kingdom there are four varieties of industrial alcohol which may be used free of tax in appropriate circumstances. The

four kinds are: (1) mineralized methylated spirit; (2) industrial methylated spirit; (3) specially-denatured alcohol; and (4) alcohol not denatured, and more particularly, methyl alcohol.

In the chief foreign manufacturing countries the arrangements for using industrial alcohol free of duty run much on the same lines as in this country, though there are, of course, differences of detail.

Uses of Industrial Alcohol. Apart from the use of alcohol as a fuel, etc., which is dealt with in the chapter on "Power Alcohol" (p. 67), the chief technical applications of alcohol are (1) as a solvent, and (2) as a raw material for conversion into non-alcoholic products.

Water is the only substance which even approaches alcohol in importance as a solvent. For many articles, however, water is valueless in this connection, and no general substitute for alcohol has yet been discovered, or is likely to be. Much the same may be said as regards the use of alcohol as a raw material. Here and there, no doubt, a substitute is available. Thus chloroform can be made from either alcohol or acetone; but even though an alternative is sometimes possible, the fact remains that, in general, alcohol is the cheapest and most convenient material.

In order to exemplify and give precision to these general statements, tables are adduced showing the purposes to which industrial alcohol is applied in the three chief European countries, with the annual quantities employed in pre-war times. From these tables we will select various typical items, and indicate more particularly how or why the alcohol is used in these instances. The pre-war data will convey perhaps a better idea of normal consumption than recent returns would show.

TABLE III

Industrial Methylated Spirit in the United Kingdom Year 1913–14

Manufacture or other purpose.	*Quantity in thousands of gallons.*
Finish, for sale	395·7
Varnish, polish, and lacquer, for sale	983·7
Stains, paints, enamels, etc.	67·5
Varnish, polish, etc., for use in makers' workshops	300·3
Felt and other hats	134·7
Celluloid, xylonite, and similar substances	28·8
Oilcloths, leather cloths, pegamoid, linoleum, etc.	221·3
Smokeless powders, fulminates, and other explosives	19·3
Soap-making	180·7
Electric lamp filaments and electric cables	14·2
Incandescent mantles	16·2
Ether	198·1
Chloroform	5·8
Ethyl chloride and bromide	0·8
Solid medicinal extracts	53·7
Alkaloids and fine chemicals	32·5
Embrocations, liniments, and lotions	34·1
Surgical dressings	10·0
Capsules and other medical appliances	2·0
Hair washes	29·5
Cattle medicines	2·5
Plant washes, insecticides, and sheep dips	10·9
Aniline and other dyes, solids	0·2
Aniline and other dyes, solutions	2·3
Fireworks and matches	3·1
Photographic plates, papers, and other photographic purposes	46·1
Steel pens	3·5
Silk, crape, and embroidery	8·5
Artificial flowers, etc.	5·0
Rubber	0·6
Artificial silk	0·8
Ships' compasses, spirit levels, etc.	1·1
Inks	0·8
Collodion	8·2
Disinfectants	2·3
Hop extract	19·0
Dyeing and cleaning operations	42·2
Carried forward	2,886·0

TABLE III

INDUSTRIAL METHYLATED SPIRIT IN THE UNITED KINGDOM
YEAR 1913–14 (*Continued*)

Manufacture or other purpose.	*Quantity in thousands of gallons.*
Brought forward	2,886.0
Textile printing	8·4
Preserving specimens in museums and hospitals	6·6
Educational and scientific purposes in colleges and schools	5·8
Analytical and scientific purposes in laboratories of analysts, works chemists, etc. . . .	5·7
Hospitals, asylums, and infirmaries . .	51·2
Electrotyping and printing	1·1
Used in dockyards and arsenals, chiefly for varnish and polish	14·9
Miscellaneous purposes	10·9
Total, in thousands of gallons . .	2,990·6

That is, the total number of gallons used was 2,990,600.

TABLE IV

INDUSTRIAL ALCOHOL, TAX FREE, IN FRANCE. YEAR 1913

Manufacture or other use.	*Quantity in thousands of gallons.*
Varnishes	363·9
Thinning purposes	22·4
Plastic materials (celluloid, etc.) . . .	395·3
Hat making	22·3
Dyes and colours	18·2
Liquid rennet	4·3
Collodion	19·1
Artificial silk	6·5
Chloroform	11·7
Chloral	1·9
Various products (alkaloids, extracts, transparent soap, etc.)	104·0
Scientific purposes	7·3
Ether, fulminates, and explosives . . .	3,704·6
Total, in thousands of gallons . .	4,681·5

In this case the quantities are expressed in terms of pure (100 per cent) alcohol, of which the total amount

used was 4,681,500 imperial gallons. The table is not quite comparable with the one preceding, inasmuch as the last item, by far the largest, includes explosives, for making which in the United Kingdom specially denatured alcohol is chiefly employed.

Besides the foregoing, more than 11,000,000 gallons of denatured alcohol were employed in France for heating and lighting purposes during the year in question. In this country, mineralized methylated spirit is used for these and other purposes, but the quantity is very much less—only about 1,750,000 gallons yearly, in fact.

TABLE V

PARTLY-DENATURED INDUSTRIAL ALCOHOL USED IN GERMANY YEAR 1912

Manufacture.	*Quantity in thousands of gallons.*
Vinegar making	3,293·6
Industrial acetic acid	72·3
Brewers' glaze	29·0
Finishing of rubber goods	1·8
Celluloid and pegamoid	921·3
Synthetic camphor	8·4
Ether	715·7
Photographic films, papers, and plates	46·4
Acetic ether	12·6
Coal-tar colours and by-products	183·3
Solutions of coal-tar colours for dye-printing	7·4
Ligatures	16·0
Chloroform	4·9
Iodoform	4·6
Ethyl bromide and bromoform	1·5
Lac dyes	91·5
Lacquers of all kinds (exclusive of lac dyes and brewers' glaze)	700·1
Scientific preparations for teaching purposes	2·0
Solid soaps	58·5
Wool fats and oils	16·7
Other purposes, including a number enumerated in regulations quoted	571·5
Total, in thousands of gallons 100% alcohol	6,759·1

Here again it will be noticed that the total quantity, 6,759,100 gallons, is very much larger than the total shown for this country in Table III, or for France in Table IV. By far the largest item, however, is the first on the list, which shows more than 3,250,000 gallons of alcohol as used for making vinegar. In this country very little alcohol is employed directly in this industry, as vinegar is made here almost entirely from malt and other materials mashed expressly for the purpose. When the quantity in question is deducted from the German total, a very different complexion is put upon the relative figures.

Making now a selection of typical items from Table III, we will proceed to show how the alcohol is applied in these manufactures.

"*Finish.*" This is a solution of resin (colophony), shellac, or other gum-resins in alcohol, and is used by furniture polishers for "finishing off" or "spiriting off" their work. It must legally, when made from methylated spirit, contain in actual solution at least 3 oz. of resin or gum-resin per gallon. Sufficient of the resinous materials must therefore be used to ensure that this proportion is dissolved, after allowing for insoluble matters contained in the materials. Finish differs from spirit varnish and polish in containing a much larger proportion of alcohol. The function of the alcohol is to dissolve the resinous substances.

Varnish, Polish, and Lacquer. These are also, in the main, solutions of resinous materials in alcohol. The chief resins or "gums" employed are ordinary resin (colophony), sandarac, copal, dammar, elemi, benzoin, shellac and acaroid resins. The proportions of these vary considerably, ranging generally from 2 to 6 lbs. per gallon. The three articles differ amongst themselves in the kinds of resins used, and in the proportions;

broadly speaking, it may be said that varnishes usually contain more resinous matter than polishes, whilst a typical lacquer, such as is used for brass work, has shellac as its resinous basis and includes colouring matters like turmeric and saffron. As an example of a *spirit varnish* the following recipe may be given—Shellac 34 oz., sandarac resin 4 oz., yellow resin 5 oz., spirit 1 gallon. A formula for *French polish* is—Shellac 32 oz., benzoin 1 oz., sandarac 2 oz., spirit 1 gallon; and a recipe for *brass lacquer* contains—Shellac 30 oz., turmeric 10 oz., annatto 2½ oz., saffron 2½ oz., and spirit 1 gallon. In making the last article the turmeric, annatto, and saffron are first extracted with the alcohol, and filtered, and the shellac dissolved in the filtrate. The solution is allowed to settle, and strained or filtered for use.

Stains, Paints, and Enamels. Alcohol is used in these for dissolving dyes and other colours, as well as any resinous ingredients which may be present. An *oak stain*, for example, is made by dissolving: Bismarck brown 2 oz., Vandyke brown 4 oz., Nigrosin dye 4 oz., in spirit, 1 gallon. A *yellow stain* is prepared by dissolving 12 oz. of gamboge in a gallon of spirit, allowing the solution to settle, and straining off the clear liquid.

Felt Hats. In the manufacture of these a kind of spirit varnish is used as a "stiffener" for the felt. Alcohol is employed to make this varnish, and also to dissolve the colouring matters used.

Celluloid, Xylonite, etc. These substances have as basic ingredients cellulose nitrates or acetates mixed with camphor and various fillings and colourings. Alcohol is employed, with amyl acetate, toluene, and other liquids, as a solvent to incorporate the materials and bring them into a plastic, workable condition.

Powders, Fulminates, and other Explosives. In these industries alcohol is used both as a solvent and as a raw material. Mixed with ether (itself produced from alcohol), it dissolves nitrocellulose (gun cotton), employed in large quantities for making smokeless powders. It was used on a large scale during the war for purifying trinitrotoluene ("T.N.T.") by crystallization. The crude T.N.T. is dissolved in warm alcohol, and allowed to cool, when it crystallizes out, leaving impurities in solution. This process is typical of a great many in which alcohol is used for the purification of crude products, in order to refine them and render them marketable.

For fulminates, alcohol serves as the basic material, not as a solvent. It is destroyed in the process of manufacture, and no longer exists as alcohol in the finished article ; but it supplies some of its components, carbon and oxygen, to form an explosive combination with the metallic ingredient in the completed fulminate. Mercury is dissolved in nitric acid, and alcohol in the requisite proportion is mixed with the solution. A chemical reaction sets in between the alcohol and the other ingredients, with the result that mercury fulminate is formed, and separates out in flakes, which are subsequently purified by washing. It is much used as a detonator for firing charges of explosives.

In this connection it may be mentioned that during the great war very large quantities of alcohol were employed as the raw material for making "mustard gas." The alcohol was converted into ethylene gas, and this, passed into sulphur monochloride, produced the poison-gas in question.

Soap Making. In preparing the so-called "transparent" or translucent soaps, alcohol is employed as a clarifying agent. Dried soap is dissolved in the spirit,

separated from insoluble impurities, and most of the alcohol distilled off. The residual mass is formed into bars or cakes and stored at the ordinary temperature, when the remaining alcohol slowly evaporates and leaves a transparent soap.

Incandescent Mantles. These are coated with collodion, as otherwise they would be too fragile for transport. The collodion is made by dissolving gun cotton in a mixture of alcohol and ether. Ingredients for increasing the brilliancy of the light are incorporated with the collodion, and are left on the filaments when the collodion is burnt away prior to the mantle being used.

Ether. Large quantities of this important product are made, alcohol being the raw material. A mixture of alcohol (5 parts) with strong sulphuric acid (9 parts) is heated in a still to a temperature of 130°–140° C. (266°–284° F.). The acid reacts chemically with the alcohol, producing ether, which distils over and is subsequently purified. The process is made continuous by running a regulated stream of alcohol into the heated mixture as fast as the ether distils away. Ether is used in large quantities as an anaesthetic, as a solvent, and in ice-making apparatus.

Chloroform. Like ether, this is largely used as an anaesthetic and as a solvent. It is made by distilling alcohol with bleaching powder, or by first passing chlorine gas into alcohol and distilling the product with bleaching powder. Acetone can be used instead of alcohol, the choice at any particular time, depending upon which of the two materials is the cheaper in relation to the yield of chloroform obtained.

Ethyl Chloride and Ethyl Bromide. These are made by distilling alcohol with, respectively, hydrochloric acid and a mixture of sodium bromide and sulphuric acid. They are employed as anaesthetics, and the

chloride is also used technically in the making of certain dyestuffs and other chemical products.

Solid Medicinal Extracts. Medicinal plants, such as aconite, aloes, belladonna, colchicum, digitalis, ergot, gentian, henbane, ipecacuanha, and so on, yield their active principles to alcohol when treated with this solvent, and a large number of spirituous extracts and tinctures of such drugs are used in medicine. The roots, barks, leaves, or other parts of the plants, suitably crushed or cut up, are macerated with alcohol of appropriate strength, or percolated with it, and the resulting extract utilized in a liquid or solid form for compounding prescriptions, making liniments, and so on.

Spirituous medicines for internal use cannot legally contain methylated spirit; they must be made with pure, and therefore duty-paid, alcohol (*see* Chapter IV, Immature Spirit). But since there is an appreciable loss of this expensive spirit in the various operations of extraction, filtration, and evaporation required in preparing the extracts, manufacturers are allowed to use the cheaper industrial methylated spirit for these preliminary operations. The spirit is then distilled completely away (and recovered for re-use), leaving behind the solid or semi-solid extract, which can now be re-dissolved in pure alcohol to make the finished product. Loss of the more expensive duty-paid spirit is thus avoided.

Alkaloids and Fine Chemicals. The alcohol in these instances is chiefly used in purifying the products, generally by crystallization from a solution of the substance in spirit more or less diluted with water. It is also employed for extracting alkaloids from the parent plants, and in making synthetic drugs such as phenacetin and antipyrin, as well as photographic chemicals and laboratory re-agents.

Embrocations and Liniments. Here the alcohol is used to dissolve the organic drug or chemical which is usually the active ingredient. Such drugs are, for example, aconite, belladonna, capsicum, opium, camphor chloroform, and iodine.

Surgical Dressings. These include such articles as iodoform gauze and capsicum wool. The gauze or wool is impregnated with a solution of the active drug (iodoform, capsicum) in alcohol, and the solvent evaporated off.

Hair Washes. Various medicaments, oils and perfumes are present in these, for which alcohol serves as a solvent. In so-called "dry" shampoo washes the spirit fulfils also the further purpose of assisting the drying of the wash after application, since it evaporates more readily than water does. In "non-separable" brilliantines the oil employed is castor oil, which dissolves in alcohol. In the "separable" varieties the oily basis is either a mineral oil, or a fixed vegetable oil such as almond or olive oil, nether of which is appreciably dissolved by alcohol; but even in these cases a small quantity of spirit is used to thin the product and to serve as a vehicle for the perfumes and colourings employed. A well-known preparation is Sir Erasmus Wilson's hair lotion, one recipe for which is as follows—Oil of almonds, 2 oz.; strong solution of ammonia, 2 oz.; honey water, 4 oz.; oil of rosemary, 1 oz.; rectified spirit, 10 oz. An example of a "Bay Rum" lotion is—Oil of bay, 10 drachms; oil of pimento, 1 drachm; extract of quassia, 1 oz.; saponin, 2 drachms; acetic ether, 2 oz.; spirit, 3 gallons; water, 2 gallons. The spirit may or may not contain a proportion of rum, at the maker's discretion. It is used for dissolving the oils and the acetic ether, whilst the quassia extract is dissolved in the water, the two solutions being then

mixed, the saponin added, and the mixture allowed to stand for a week or two. It is then filtered for use.

Aniline Dyes, Solids. In making various "intermediate" products for these, alcohol serves as the raw material. The principal articles are compounds formed by combinations of aniline with methyl alcohol or ethyl alcohol, namely monomethylaniline, dimethylaniline, diethylaniline, and ethyl benzylaniline. The "intermediates" themselves are subsequently combined with other chemical substances to produce the finished dyestuffs, such as methyl violet, brilliant green, ethyl purple, and so on.

Photographic Plates, etc. The photographer uses alcohol for making the gelatine or collodion emulsions with which plates or papers are coated, and also for the rapid drying of plates and papers.

Steel Pens. Here the alcohol is employed for making the varnish or lacquer in which the pens are dipped.

Artificial Flowers. These are coloured with spirit-dyes, and the alcohol is used as a solvent for the dye.

Artificial Silk. The basis of this is a nitro-cellulose or acetyl-cellulose, which is dissolved in a mixture of alcohol (2 volumes) and ether (3 volumes), forming a kind of collodion. The solution is forced through a series of tubes, eventually emerging in the form of thin filaments, which rapidly dry, and are spun together to make the "silk" thread.

Ships' Compasses. The alcohol is used, either alone or mixed with water or glycerin as required, to form a non-freezing liquid of suitable specific gravity in which the compass is floated.

Dyeing and Cleaning. In dyeing and textile printing, alcohol is employed as a solvent for the dye or colour used. In cleaning fabrics, it and other solvents, as

the case may require, are employed for removing grease-spots, fruit-stains, and other discolorations.

Without further labouring the point, the foregoing examples will serve to show how many and various are the uses to which industrial alcohol is put in subserving the every-day requirements of modern industry.

CHAPTER VI

POWER ALCOHOL

In the year 1919 we imported into the United Kingdom some 200,000,000 gallons of petrol, the bulk of which was used for driving motor vehicles. The consumption of petrol for this purpose has been steadily increasing. A decade or so ago it was about 60,000,000 gallons; by 1915 it had risen to 120,000,000 gallons; it was 193,000,000 in 1918; and it is now (1920) upwards of 200,000,000 gallons,

Much the same story is told in other countries. With the development of motor transport the demand for motor-spirit increases from year to year.

Meanwhile the sources of crude petroleum, from which petrol is distilled, are gradually being depleted, so that it becomes more and more difficult to meet the demand. Approximately three-fourths of the world's supplies of crude petroleum are contributed by the United States. The Geological Survey of that country, after carefully reviewing the position, concludes that the maximum output will be reached very shortly—in fact, within two or three years—and thenceforward there will be a gradual decline. According to an official estimate made a few years ago, the older American oilfields will become exhausted in about thirty years time.

Naturally, this estimate will need some revision if any important new field should be discovered; but with this reservation, the outlook appears to be fairly indicated in the foregoing paragraphs.

In these circumstances, and in view of the great importance of motor transport, it is not surprising that attention should have been drawn to the possibility of using alcohol as a motor fuel. In doing this there would be one very notable advantage. Vegetable raw materials for making alcohol can be grown in widely-different climates, from temperate to tropical, and *the supplies could be constantly renewed.* There would be no question of the sources becoming exhausted, as is the case with petroleum. Starch-bearing plants like maize, cassava, arrowroot, and potatoes can be grown wherever suitable land and the requisite labour to till it are available. Their energy of growth is drawn from the sun ; and with sunshine ever recurring as the seasons roll, these and other suitable crops can be obtained as long as it is worth anyone's while to raise and garner them. With the price of petrol soaring as the demand outstrips the supply, it probably will be more and more worth while to grow starch crops and sugar crops in excess of food requirements in order to meet the demand for alcohol as a motor fuel.

For the driving of motor engines, alcohol is applied in a manner quite similar to that in which petrol is used. Its vapour, mixed with a due proportion of air, is drawn into the cylinder of the engine, where it is first compressed and then ignited. The explosive combustion which results generates heated gases. The pressure of these propels the piston, and so works the engine.

Alcohol is not so volatile as petrol ; it does not so readily give off vapour. This is a disadvantage in connection with its use as a motor fuel, since it makes the engine more difficult to start, especially in cold weather. Unless the fuel in the cylinder has a vapour tension greater than a certain limit, the mixture of air and vapour does not explode. Hence it is easier to start

the engine with petrol than with alcohol, because the former is the more volatile ; it gives off more vapour at any particular temperature. The difficulty is obviated, when using alcohol, by pre-heating the carburettor with a torch ; or by mixing a volatile substance such as ether or petrol with the alcohol ; or else by employing petrol or benzol as a starter "from cold," and turning on the alcohol when the cylinder has become warmed up.

An official Committee which examined the question of using alcohol in petrol engines reported as follows : "When alcohol is used in an ordinary petrol engine the consumption of fuel per brake horse power is about 50 per cent greater than in the case of petrol. It appears, however, that the consumption of alcohol in a *specially designed alcohol engine* will not exceed the consumption of petrol in a petrol engine.

"The main alterations necessary in the ordinary design of petrol engines in order to fit them to work efficiently on alcohol are as follow, viz. : (*a*), an increased compression from about 75 lb. per square inch, which is the average for petrol engines, to about 180 lb. per sq. in., both above atmospheric pressure : (*b*), a pre-heating of either the fuel or the air, or of the mixture of fuel and air ; and (*c*), an increase in the area of the fuel jets and fuel supply pipes."

As a fact, a good deal of alcohol has actually been used as motor fuel. No doubt much remains to be said and done before the perfect alcohol engine is evolved ; but the matter has passed out of the purely experimental stage. In general the alcohol is mixed with other liquid fuels, of which the principal are benzol, petrol, and ether, though others, such as acetone, kerosene, and fusel oil alcohols, have also been advocated. Equal parts of alcohol and benzol ; or alcohol (2 parts),

benzol (1 part), and ether (1 part), have given good results on the Continent ; whilst in South Africa a mixture termed "natalite," containing about 40 per cent of ether to 60 of alcohol, has been used ; and a mixed fuel composed of alcohol, ether, and benzol is being employed experimentally in the United States postal aeroplane service. In the last mentioned case the tests have shown that there was much less carbon deposit with alcohol than with petrol, so that the engine cylinders and the sparking-plugs were kept cleaner, and forced landings due to fouled plugs were reduced to a minimum. Further, the consumption of lubricating oil was notably less than when petrol was used, and there was a marked increase in the number of miles flown per gallon of fuel burned. For a flight of given distance and altitude, only about four-fifths as much alcohol fuel was required, as compared with petrol.

The following comparative results, showing, for motor vehicles, the distance travelled per litre of fuel used, were published on the Continent in 1917—

Fuel.	*Kilometres travelled.*
Alcohol alone	5·4
Petrol ,,	5·8
Benzol ,,	7·1
Alcohol and benzol, equal parts	7·5
Alcohol, 3 parts ; benzol, 1 part	7·0

An earlier series of tests, made in this country to compare the relative amount of power obtained and volume of fuel used, may also be quoted. The fuels tested were petrol, benzol, and mixtures of benzol with mineralized methylated spirit. The experiments were made with a four-cylinder engine running at 1,000 revolutions per minute. Petrol (specific gravity 0·710) was taken as the standard, and the results obtained

with the other fuels were compared with those given by petrol reckoned as 100. The comparison is shown below.

Fuel tested.	Power obtained.	Volume of fuel used.
(1) Petrol	100	100
(2) Benzol	98·2	84·5
(3) Methylated spirit 1 part, benzol 1 part	99	96·3
(4) Methylated spirit 2, benzol 1 .	92	108·9
(5) ,, ,, 3, ,, 1 .	91·5	124·5

If we compare the results given by the three mixtures of methylated spirit and benzol, we see that No. 3, consisting of equal parts of spirit and benzol, is a much better fuel than either of the other two. Mixtures such as the above, where the alcohol is mixed with benzol or other liquid hydrocarbons, are often referred to as "carburetted" alcohol.

As regards mixtures of alcohol with liquid hydrocarbons such as petrol or kerosene, it is important to note that they should be homogeneous mixtures, if they are to be used as liquid fuels. They must not be mixtures which would settle out into two or more layers on standing, either in the course of ordinary usage or when exposed to unusually low temperatures, as during hard frosty weather. If such a separation into layers occurred, it would mean difficult or even impracticable working, since there would be two or more different kinds of fuel for the carburettor to deal with—a light kind at one period of a run, and a heavier kind at another period. In this connection the following facts may be mentioned—

(1) The solubility of a hydrocarbon fuel in alcohol is greater the lighter the hydrocarbon is. Petrol, for instance, is more soluble than kerosene.

(2) The solubility is considerably affected by the presence of water. That is, it depends upon the strength of the alcohol.

Thus at the freezing point of water (0° C. or 32° F.), absolute alcohol and the liquid hydrocarbon heptane are miscible with one another in all proportions. With 95 per cent alcohol, complete miscibility is only obtained when there is not more than about 30 per cent of heptane present ; whilst with 90 per cent alcohol the proportion of heptane must not exceed 11 per cent.

Both petrol and kerosene are only soluble in alcohol to a relatively small extent. Hence no large proportion of either can be employed in mixture with alcohol alone, if separation is to be avoided.

This difficulty may be overcome, by adding to the mixture a certain proportion of some third fuel, such as benzol or ether, which will dissolve both of the other constituents. The quantity of benzol (or ether) added should be sufficient to maintain the mixture of fuels completely homogeneous under all conditions of temperature in which it is likely to be used.

Here again the strength of the alcohol is of importance. The lower this strength is, the greater will be the proportion of benzol which must be added to a given mixture (say petrol and alcohol) in order to obtain a homogeneous liquid. This is well shown by the following results of a series of experiments made for the purpose of testing the point in question.

Mixtures of alcohol and petrol were made, containing two parts of the former to one part of the latter, by volume. The strength of the alcohol varied from 95 per cent down to 90 per cent in the various mixtures. Using 100 volumes of mixture, the quantity of benzol required to be added, in order to produce a homogeneous

liquid, was determined for each strength of alcohol. The results may be shown thus—

TEMPERATURE 0° C.

Strength of alcohol (by volume) per cent.	*Volume of benzol necessary to produce a homogeneous mixture.*
95	12
94	19
93	27
92	35
91	65
90*	

Hence for such mixtures of liquid fuels it is desirable to use alcohol at as high a strength as is practicable. Ninety per cent alcohol would not serve with the particular mixture described above ; the nearer 95 it is, the better the result.

A good method of raising the strength of 90 per cent alcohol is to distil it over calcium carbide.

It should perhaps be mentioned that petrol varies in quality, and the figures given above would probably not apply strictly to all qualities. They will, however, indicate broadly the kind of results to be expected with alcohol-petrol-benzol mixtures generally.

Following are some thermal and other particulars of mineralized methylated spirit (J. S. S. Brame, *Fuel*).

Specific gravity . . . . 0·820 to 0·827
Percentage composition : Carbon, 50·7 ; Hydrogen, 13·0 ; Oxygen, 36·3.
Calorific value, British Thermal Units—
Per lb., gross value . . 11,320
Per lb., net value . . 10,350
Air required for combustion, theoretical quantity, per gallon, 930 cu. ft. at 60° F.

This mineralized methylated spirit is, at the time of writing, the only kind of duty-free alcohol which can legally be used for fuel purposes in the United Kingdom.

* No homogeneous mixture possible.

It contains, however, a relatively large proportion (10 per cent) of wood naphtha as principal denaturant (*see* Chapter V), and this is a rather expensive ingredient. Hence statutory powers have been obtained by the authorities to modify the composition and proportions of the denaturants, so that a "power methylated spirit" may be produced in which cheaper denaturing ingredients will partly replace the relatively scarce and rather costly wood naphtha. Up to the present these modifications have not been announced, but there is no reason to doubt that a power alcohol with less expensive denaturants will in due course be authorized for use in this country.* Alcohol for power purposes should obviously be as cheap as possible.

It is not very likely that the quantity of alcohol necessary to make us independent of petrol, or even to replace it in any substantial degree, will be produced from materials grown in this country. The cost would probably be too high. We have insufficient acreage available; the cost of cultivation, harvesting, and manufacture is too great; and the most suitable materials are also important foodstuffs, from which no considerable amounts could be spared for the purpose. Barley, potatoes, and mangolds are the types of vegetable products, suitable for making alcohol, which we could grow here. It has been calculated that, to obtain the 250,000,000 gallons of alcohol which would, roughly, be equivalent to our annual consumption of petrol, we should need more than 4,000,000 tons of barley, or 12,500,000 tons of potatoes, or 25,000,000 tons of mangolds. But the total annual production of potatoes

* A formula for power methylated spirit has now been authorized. To 100 volumes of 95 per cent alcohol are added 2½ volumes of wood naphtha, ½ volume of crude pyridine, not less than 5 volumes of benzol, and sufficient dye to give the mixture a pink tint.

in the United Kingdom is only one-half, and of the other two materials barely one-third, of these quantities. The barley we produce is already largely used in the making of malt ; the potatoes and mangolds are foodstuffs. Since this country is very far from being self-supporting in the matter of food, no considerable proportion of these crops could be diverted to increase the production of alcohol. They command a much higher price as foodstuffs than could be paid for them as sources of power alcohol.

In tropical and sub-tropical countries, where land is plentiful, labour cheap, and sunshine abundant, it may be quite practicable to grow vegetable substances like cassava, arrowroot, and maize at such a cost as will make them very important sources of power alcohol, Maize has, indeed, been much used for this purpose in the past, but at present its price precludes its employment on a large scale. Still, there are regions—as, for example, in South Africa and South America—where two or even three crops of maize can be secured yearly, and with proper organization this raw material could, under conditions of mass-production, become one of the most important sources of supply. Rice straw, again, is a cheap material available in large quantities ; and if the method of utilizing it described in Chapter III should prove to be successful, this and similar cellulosic substances may also become factors of some value in the problem of producing alcohol cheap enough to be used as fuel. Molasses, cane-sugar juice, and palm sap are also important, though restricted, tropical sources of supply.

Thus the question of power alcohol largely resolves itself, so far as this country is concerned, into a matter of getting sufficient supplies of cheap raw materials by organizing and developing overseas resources.

We could produce here 100,000,000 gallons more than our present output if we could devote 500,000 acres of land to raising mangolds for the purpose; or if, with our present acreage of potatoes, we could increase the yield of this crop from the present 5¼ tons to about 9 tons per acre. Lacking some such measures as these, we must depend upon importations, either of the raw materials or of the alcohol itself, for any very considerable increase in our supplies of power alcohol.

We may note here certain conclusions arrived at by a Committee on Alcohol Motor Fuel which reported officially on this subject in June, 1919—

"All sales and deliveries of power alcohol should be made on the basis of a certified percentage by volume of absolute ethyl alcohol, with a minimum of 90 per cent at a temperature of 62° F.

"We are of the opinion that in denatured alcohol, or in mixtures of alcohol, benzol, ether, petrol, or the like, sold as power alcohol, the ratio of water to alcohol after admixture should not exceed one part by volume of water to nine parts by volume of alcohol, measured at the ordinary temperature.

"We further consider that when benzol, ether, petrol, or the like, are mixed with alcohol in quantities in excess of those which may be legally required as partial denaturants, the nature and amounts per cent by volume of such components spould be plainly stated on the containers of such mixtures and on the contracts, sales-notes, and invoices dealing therewith."

CHAPTER VII

ALCOHOLOMETRY

An important thing in connection with alcohol is to know how it is measured. The reader is already familiar with the fact that alcohol, as ordinarily met with, always contains more or less water. To produce it entirely free from water is very difficult ; and in fact, alcohol which is strictly " absolute " is not required in commerce or industry. It is found only in the laboratory and but rarely even there. Any spirituous liquid we deal with, whether as a beverage, or in the arts, or in manufactures, is practically always a mixture of alcohol and water at least, and may often contain other substances as well. Hence it becomes important to know *how much* alcohol the liquid contains, or what is its alcoholic " strength."

In the olden times, when alchemists " scorned delights and lived laborious days " in search of the philosopher's stone and the elixir of life, various rough-and-ready methods were employed for testing the strength of spirits. One of these alchemists, Raymond Lully, directed his readers to moisten a piece of cloth with the *aqua vitae* (the spirit to be tested) and apply a lighted taper to it. If the cloth ignited, the spirit was to be considered as *aqua vitae rectificata,* or strong alcohol. A method of testing spirit with oil was also in vogue. Some oil was poured into the spirit ; if the latter was strong, and therefore of low specific gravity, it floated on the surface of the oil ; if weak, and therefore heavy, it remained underneath the oil.

Another alchemist, Basil Valentine, who flourished

in the fifteenth century, described a mode of testing alcohol by deflagration. He judged the strength of *aqua vitae* by igniting a definite volume of it. If the whole burned away, it was pure spirit; if more than half burned off, the spirit was strong; if less than half, it was weak, and needed further rectification.

Later on, the gunpowder "proof" test came into use. A little powder was moistened with spirit, and a light applied. If rapid combustion followed, the spirit was "high proof." If the powder did not burn, or burned only with difficulty, the spirit contained too much water; it was weak. On the other hand the spirit was regarded as "good, rightfull, and of vertue" when the mixture burned steadily, even if slowly.

The development of more precise methods of assaying alcohol was largely due to fiscal requirements following upon the taxation of spirituous liquors. In the year 1666 some friction occurred between importers of French brandy and the Customs officials of this country, the point of dispute being the rate of duty chargeable on the brandy. There were two rates, 4d. and 8d. per gallon, for liquors of different qualities; and the revenue officers, guided by the sense of taste in levying the duties, decided that French brandy ought to pay the higher amount. This decision was contested by the importers, but it was eventually ratified and made statutory by an Act of Parliament passed in 1670. Presently, however, fraudulent merchants attempted by various devices to disguise the real strength of their brandies, so that other tests besides that of the palate had to be employed, and recourse was had, at first, to those mentioned above. But these tests were crude; the results were often capricious; and the need for better methods of evaluation became more and more apparent as the importance of spirit taxation increased.

Towards the close of the century, therefore, a good deal of attention was devoted to the question of obtaining a hydrometer suitable for testing spirits. Sir Robert Boyle, the distinguished philosopher, appears to have been the first to apply the principle of the hydrometer to the testing of distilled liquors. A description of his instrument ("Boyle's Bubble") appears in the *Philosophical Transactions* of the Royal Society for 1675. The genial gossip Samuel Pepys, however, makes mention of having seen the instrument some eight years earlier. "Many other pretty things he showed me," says Pepys, "and did give me a glass bubble to try the strength of liquors with."

Hydrometers are based upon the famous principle of Archimedes, that a body immersed in a liquid loses a part of its weight equal to the weight of the liquid displaced. Suppose we have a hollow bulb of glass or metal, say, two cubic inches in volume, which weighs exactly as much as one cubic inch of water. When such a bulb is placed in water, it will sink until one-half is immersed, since it will then have displaced a volume of water (1 cu. in.) equal in weight to its (the bulb's) own weight. If the bulb is placed in a liquid lighter than water, it will sink further, since more of the lighter liquid must be displaced to support the same weight. A hydrometer is essentially such a bulb, provided (1) with a graduated stem to show *how far* it sinks when placed in various liquids; and (2) with a ballast of mercury, shot, or other material to keep it upright when floating.

Boyle's hydrometer was composed of two glass bulbs surmounted by a glass stem. The lower bulb was a small one containing mercury to serve as ballast. When the instrument was placed in water, it sank only so far as to cover the two bulbs, leaving the whole of the stem exposed. In strong spirit, it sank till only the top of the

stem was left uncovered. In mixtures of spirit and water it sank to intermediate positions: the larger the proportion of alcohol, the deeper the "bubble" sank.

Later, the stem of the instrument was roughly graduated by means of "small bits of coloured glass, stuck on the outside," or it was marked off into degrees by lines. Various improved forms of the instrument were introduced as time went on, the chief improvement being the addition of detachable weights at the bottom of the hydrometer, in order to permit of its use with a larger range of liquids. Eventually, in 1802, a hydrometer devised by Bartholomew Sikes was selected as the most suitable for fiscal purposes, and this instrument remains to-day the official hydrometer for spirit assaying in this country and in British Overseas Possessions. Different forms of the instrument are used in foreign countries, but all are based on the general principle described above.

This principle, it will be noted, is founded upon the two facts: (1), that the specific gravity of mixtures of alcohol and water varies according to the proportion of alcohol present; and (2), that the hydrometer can be used to ascertain the specific gravity. Before describing Sikes's hydrometer more particularly, it will be well to consider the first part of the question—of the specific gravity—a little more closely.

The specific gravity of alcohol at the temperature 15·6° C. (60° F.) is 0·79359, water at the same temperature being taken as 1. Mixtures of alcohol and water have therefore specific gravities intermediate between these limits. But on account of the contraction which occurs when alcohol and water are mixed (*see* page 39), the specific gravities of such mixtures are not strictly proportional to the quantity of alcohol present. Hence this quantity cannot be *calculated* from a knowledge of

the specific gravity of alcohol, of water, and of the mixture. It is necessary to determine, by actual experiment, how much alcohol there is in any mixture of alcohol and water having a given specific gravity ; or, conversely, to make mixtures containing known proportions of alcohol and water, and determine the corresponding specific gravities experimentally. When this has been done, with sufficient accuracy, the results can be tabulated once for all, and used subsequently to find exactly how much alcohol is contained in any mixture of alcohol and water. We have simply to determine the specific gravity of the given mixture, and then refer this specific gravity to the table of results, which will show the corresponding quantity of alcohol. For example, it has been found by experiment that a mixture made up of equal parts by weight of alcohol and water has, at 15·6° C., the specific gravity 0·9182. If, therefore, we are given an unknown mixture of alcohol and water, and find that it has the specific gravity 0·9182, we know from the recorded experiment just mentioned that our mixture contains 50 per cent of alcohol by weight.

It is in this way that tables of alcoholic strengths have been constructed. A large number of mixtures have been made up, containing known weights of alcohol mixed with known weights of water ; and the corresponding specific gravities of these mixtures have been ascertained with the greatest possible accuracy at selected temperatures. The results have been carefully recorded, and embodied in tables suitable for everyday use in finding the alcohol content of spirituous liquids, from the weakest to the strongest.

To construct such tables with the requisite degree of precision is a laborious task. Much time and work have been expended on it, both here and abroad. The chief names to mention in this connection are those of

Gilpin and Drinkwater in this country, of Gay-Lussac in France, of Tralles in Germany, and of Mendeléeff in Russia. Gilpin, indeed, may be described as the founder of alcoholometry. He was the clerk to the Royal Society, which body had been asked by the Government, in the latter part of the eighteenth century, to advise them and to assist in ascertaining what was "the best method of proportioning the Excise on Spirituous Liquors." The secretary of the Society, Dr. Chas. Blagden, reported (1790) that "no method can be accurate except one based upon specific gravities"; and Gilpin carried out the necessary experimental work. The results were published (1794) in the *Philosophical Transactions* of the Royal Society.

We cannot stop to trace here the development of alcoholometry during the intervening period; but it may be said that the appended alcohol table is an abbreviation of revised tables issued a few years ago, and that in the revision the work of Blagden and Gilpin, Drinkwater, Mendeléeff, and a German official commission was utilized. It thus sums up, as it were, the best work of the world's most accurate experimenters in this domain. Needless to say, the complete table is very much more extensive, and should be consulted when more minute particulars are required.

In using this, or any similar alcohol table, it is particularly to be noted that the liquid to be tested must not contain anything except alcohol and water. At all events, if any other substances are present, the quantities must be so small that they do not appreciably affect the specific gravity. Hence if such articles as beer, wine, sweetened gin, tincture of opium, or spirit of camphor are being dealt with, the alcohol must be separated from the other ingredients (except water) before its quantity can be determined by means of the

TABLE VI

Specific Gravity of Aqueous Alcohol at 60°/60° *F.* (15·6°/15·6° *C.*)

Specific gravity.	Per cent by volume.	
	Alcohol.	Proof spirit.
0·794	99·9	175·2
5	99·7	174·9
6	99·5	174·5
7	99·3	174·2
8	99·1	173·8
9	98·9	173·4
0·800	98·7	173·1
1	98·5	172·7
2	98·3	172·3
3	98·1	171·9
4	97·8	171·6
5	97·6	171·2
6	97·4	170·8
7	97·2	170·4
8	96·9	170·0
9	96·7	169·5
0·810	96·5	169·1
1	96·2	168·7
2	96·0	168·3
3	95·7	167·8
4	95·5	167·4
5	95·2	167·0
6	95·0	166·5
7	94·7	166·1
8	94·5	165·6
9	94·2	165·1
0·820	93·9	164·7
1	93·7	164·2
2	93·4	163·7
3	93·1	163·2
4	92·8	162·8
5	92·6	162·3
6	92·3	161·8
7	92·0	161·3
8	91·7	160·8
9	91·4	160·2
0·830	91·1	159·7

Specific gravity.	Per cent by volume.	
	Alcohol.	Proof spirit.
0·831	90·8	159·2
2	90·5	158·7
3	90·2	158·2
4	89·9	157·6
5	89·6	157·1
6	89·3	156·6
7	89·0	156·0
8	88·7	155·5
9	88·4	154·9
0·840	88·1	154·4
1	87·7	153·8
2	87·4	153·3
3	87·1	152·7
4	86·8	152·1
5	86·5	151·6
6	86·1	151·0
7	85·8	150·4
8	85·5	149·8
9	85·1	149·2
0·850	84·8	148·6
1	84·4	148·0
2	84·1	147·4
3	83·8	146·8
4	83·4	146·2
5	83·1	145·6
6	82·7	145·0
7	82·4	144·4
8	82·0	143·8
9	81·7	143·2
0·860	81·3	142·5
1	81·0	141·9
2	80·6	141·3
3	80·3	140·7
4	79·9	140·0
5	79·5	139·4
6	79·2	138·7
7	78·8	138·1
8	78·4	137·5
9	78·1	136·8

TABLE VI (*contd.*)

Specific Gravity of Aqueous Alcohol at 60°/60° *F.* (15·6°/15·6° *C.*)

Specific gravity.	Per cent by volume.		Specific gravity.	Per cent by volume.	
	Alcohol.	Proof spirit.		Alcohol.	Proof spirit.
0·870	77·7	136·2	0·910	61·5	107·7
1	77·3	135·5	1	61·1	107·0
2	76·9	134·8	2	60·6	106·2
3	76·6	134·2	3	60·2	105·4
4	76·2	133·5	4	59·7	104·6
5	75·8	132·9	5	59·3	103·8
6	75·4	132·2	6	58·8	103·1
7	75·1	131·5	7	58·4	102·2
8	74·7	130·9	8	57·9	101·4
9	74·3	130·2	9	57·5	100·6
0·880	73·9	129·5	0·920	57·0	99·8
1	73·5	128·8	1	56·5	99·0
2	73·1	128·1	2	56·1	98·2
3	72·7	127·5	3	55·6	97·3
4	72·3	126·8	4	55·1	96·5
5	72·0	126·1	5	54·6	95·6
6	71·6	125·4	6	54·1	94·8
7	71·2	124·7	7	53·7	94·0
8	70·8	124·0	8	53·2	93·1
9	70·4	123·3	9	52·7	92·2
0·890	70·0	122·6	0·930	52·2	91·4
1	69·6	121·9	1	51·7	90·5
2	69·1	121·1	2	51·2	89·6
3	68·7	120·4	3	50·7	88·7
4	68·3	119·7	4	50·2	87·8
5	67·9	119·0	5	49·6	86·9
6	67·5	118·3	6	49·1	86·0
7	67·1	117·5	7	48·6	85·0
8	66·7	116·8	8	48·0	84·1
9	66·3	116·1	9	47·5	83·2
0·900	65·8	115·3	0·940	47·0	82·2
1	65·4	114·6	1	46·4	81·2
2	65·0	113·8	2	45·9	80·3
3	64·6	113·1	3	45·3	79·3
4	64·1	112·4	4	44·7	78·3
5	63·7	112·0	5	44·1	77·2
6	63·3	111·6	6	43·5	76·2
7	62·8	110·1	7	43·0	75·2
8	62·4	109·3	8	42·4	74·1
9	62·0	108·5	9	41·8	73·1

TABLE VI (*contd.*)

Specific Gravity of Aqueous Alcohol at 60°/60° *F.* (15·6°/15·6° *C.*)

Specific gravity.	Per cent by volume.		Specific gravity.	Per cent by volume.	
	Alcohol.	Proof spirit.		Alcohol.	Proof spirit.
0·950	41·1	72·0	0·976	20·0	34·9
1	40·5	70·9	7	19·0	33·1
2	39·9	69·8	8	18·0	31·4
3	39·2	68·6	9	17·0	29·7
4	38·6	67·5			
5	37·9	66·3	0·980	16·0	28·0
6	37·2	65·1	1	15·1	26·3
7	36·5	63·9	2	14·1	24·7
8	35·8	62·6	3	13·2	23·0
9	35·1	61·3	4	12·3	21·4
			5	11·4	19·9
0·960	34·3	60·0	6	10·5	18·3
1	33·6	58·7	7	9·7	16·9
2	32·8	57·3	8	8·8	15·4
3	32·0	55·9	9	8·0	13·9
4	31·2	54·5			
5	30·3	53·0	0·990	7·2	12·5
6	29·5	51·5	1	6·4	11·2
7	28·6	50·0	2	5·6	9·8
8	27·7	48·4	3	4·9	8·5
9	26·8	46·8	4	4·1	7·2
			5	3·4	6·0
0·970	25·8	45·1	6	2·7	4·7
1	24·9	43·5	7	2·0	3·5
2	23·9	41·8	8	1·3	2·3
3	22·9	40·1	9	0·7	1·2
4	22·0	38·4			
5	21·0	36·6	1·000	0·0	0·0

specific gravity table. Usually it is distilled off, thus removing sugars, opium, or other solid matters. Substances which, like camphor and essential oils, cannot be eliminated in this way, must be extracted with suitable solvents, or separated by other appropriate means.

Having then, by one method or another, obtained the alcohol free from interfering substances, its specific gravity is taken, and referred to the table in order to

ascertain the proportion present. To determine the specific gravity, a suitable hydrometer may be used, or a spirit balance ; or a pyknometer (specific gravity bottle or tube), according to the degree of accuracy required.

The following examples will illustrate the procedure.

(1) Suppose we have a sample of plain spirit, as sent out from the distillery, and wish to ascertain its strength.

In this case there are no solid matters, essential oils, or other substances present to interfere with the specific gravity, so that no preliminary distillation or other treatment is required. We, therefore, determine the specific gravity at 60° F., by means of a suitable hydrometer, balance, or pyknometer. Let the result be, say, 0·8180. On reference to the table (p. 83) we see that this corresponds with 94·5 per cent of alcohol by volume, or 165·6 per cent of proof spirit.

If the specific gravity had been, say, 0·8185, then since this is between 0·818 and 0·819, the percentage of alcohol lies between 94·5 and 94·2, and a simple interpolation shows it to be 94·35.

(2) Suppose we have a sample of port wine. In this case the specific gravity of the liquor as it stands will be no indication at all of its alcoholic strength, because port wine contains not only the natural acids, tannins, and unfermented sugars of the grape juice, but varying amounts of added sugar as well ; and all these increase the specific gravity. It is therefore necessary to distil the wine, in order to separate the alcohol (and incidentally water) from these other constituents.

A definite volume of the port—say 100 cu. centimetres—at 60° F. is taken, and distilled until about three-fourths of the liquid has been collected. The distillate, which will contain all the spirit, is made up with distilled water to the exact original volume at 60° F., and the

specific gravity taken at this temperature. Let this be, for instance, 0·9785 ; then a reference to the table as before will show that the strength of the wine is 17·5 per cent of alcohol by volume, or 30·5 per cent of proof spirit.

In passing, it may be mentioned that in commercial practice it is usual to refer the specific gravities of spirituous liquids to that of water taken as 1,000, instead of 1 ; so that the above-mentioned figure would be expressed as 978·5, not as 0·9785. This is convenient, as it avoids the use of too many decimals.

Let us return now to Sikes's hydrometer. This consists of a gilded brass bulb, 1½ in. in diameter, surmounted by a graduated stem 3½ in. long, and carrying at its lower part a short, tapering rod ending in a pear-shaped counterpoise. A series of nine small weights is provided ; these can be slipped upon the rod to increase the weight of the instrument, and so allow of its being used for testing spirits of a wide range of specific gravity, and therefore of alcoholic strength.

When the instrument, with a suitable weight attached, if necessary, is placed in a sample of alcohol, it sinks until the surface of the liquid cuts some point of the graduated stem. The reading thus obtained is termed the "indication." A table is supplied with the hydrometer, showing the strength of spirit corresponding with the various "indication" numbers for a series of temperatures ranging from 30° F. to 100° F. Hence all that is necessary is to refer the "indication" to the proper table, corresponding with the temperature of the alcohol under test, and the strength of the spirit is found at once.

In Sikes's tables the strength is given in terms of degrees "over proof," "proof," or "under proof," and these are the commercial expressions employed in

this country in connection with spirituous beverages. A much shortened table is adduced here by way of illustration—

TABLE VII

SIKES'S SYSTEM

TEMPERATURE 60° F.

Hydrometer Indication.	*Strength*
	Over proof.
0	66·7
10	58·4
20	48·9
30	38·0
40	26·0
50	12·9
	Under proof.
60	1·7
70	18·6
80	40·3
90	71·9
100	100·0

Thus, if the indication is 30, the corresponding spirit strength is 38·0 O.P.—i.e. the specimen tested contains alcohol equivalent to 138·0 per cent of proof spirit. If the indication is 80, the strength is 40·3 U.P., and the alcohol present is $= 100 - 40{\cdot}3 = 59{\cdot}7$ per cent of proof spirit.

Sikes's hydrometer does not show directly the specific gravity of the alcohol tested, and it is therefore necessary to have the special tables which are supplied with the instrument. When the specific gravity is required, however, it can be obtained indirectly by first ascertaining the alcoholic strength with the hydrometer and its special table, and then referring this strength to the ordinary alcohol table (p. 83).

Experiments have also been made to determine the specific gravities which correspond with the indication numbers of Sikes's hydrometer. The results have been utilized in constructing a table to show, from the

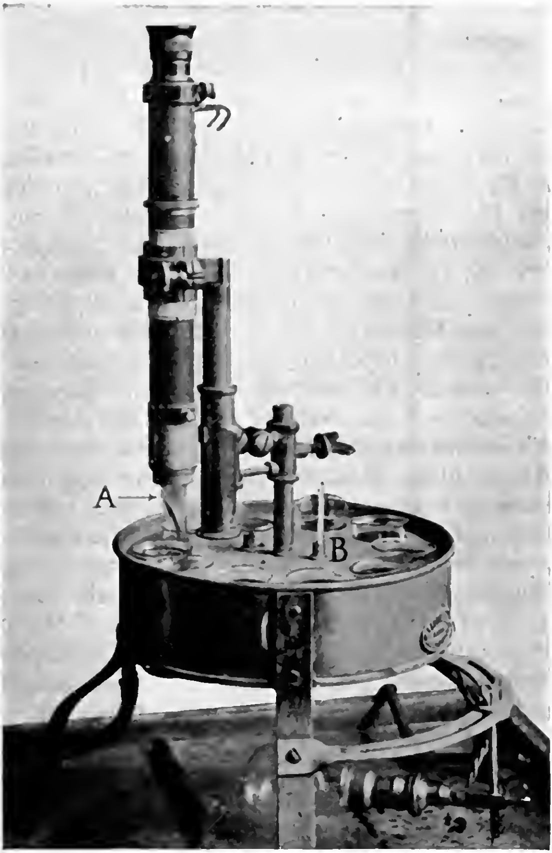


Fig. 9

IMMERSION REFRACTOMETER WITH ROTATING BATH

A = prism whose refractive surface is immersed in the liquid in the glass beneath;
B = bath with thermometer.

Light passes through a window in the bottom of the bath and, after a simple adjustment of the instrument, the scale reading is observed through the telescope. The scale reading, referred to in the tables, gives the alcoholic strength of the solution examined.

indication, the weight of spirits per gallon. This method is much used by revenue officials for ascertaining the volume of spirits in casks. The table is too long to quote here, but a simple illustration will explain its use. By weighing the cask before and after filling the weight of the spirit is obtained in pounds. Suppose this weight to be, for example, 583 lb. If the indication is, say, 10, the weight of the spirit *per gallon* is 8·326 lb., from the table in question. Then, dividing this number into 583, we get $583 \div 8{\cdot}326 = 70{\cdot}0$, the number of bulk gallons of spirit in the cask.

Hydrometers for spirit-assaying in other countries are constructed on essentially the same principle as Sikes's instrument, but differ in the methods of expressing the results. Thus in France, where Gay Lussac's hydrometer is used, the instrument denotes percentage of absolute alcohol by volume. In Germany, the hydrometer employed shows the percentage of alcohol by weight. In the United States, the results are given in terms of proof spirit, but the strength of this proof spirit is different from that adopted in this country. It contains, in fact, 50 per cent of alcohol by volume, whereas British proof spirit contains 57·1 per cent.

A brief reference to the application of the refractometer to spirit-assaying may be made.

The refractive indices of aqueous solutions of alcohol throughout the entire range of strengths between water and absolute alcohol have been determined, and tables have been constructed correlating the scale degrees of the particular refractometer used with the refractive indices, and the alcoholic strengths, of the solutions. (*See* Fig. 9.) The author's larger treatise may be consulted for details and applications of the method.

Some useful rules and examples of alcohol calculations will be found in Chapter IX.

CHAPTER VIII

METHYL ALCOHOL AND HIGHER ALCOHOLS

(1) **Methyl Alcohol.** In the introductory chapter it was pointed out that, besides ordinary or "ethyl" alcohol, many other bodies are known which, chemically, belong to the same class of substances, and are therefore likewise termed "alcohols." No doubt it is true that ethyl alcohol is far and away the most important member of the class, but there is at least one other which is of quite considerable significance commercially. This is the liquid known as "wood spirit" or methyl alcohol.

As the former of these two names indicates, this product is obtained from wood. It does not, however, exist ready formed in wood. It is produced by the decomposition of some of the woody constituents under the action of heat, when wood is "dry distilled" with exclusion of air. In much the same way coal tar, for example, does not pre-exist in coal, but is formed when coal is distilled in retorts. If either wood or coal is heated to a sufficient temperature in the open air it will, of course, eventually take fire and burn. The oxygen of the air combines with the carbon and hydrogen of the wood or coal, and the greater part of these is lost as carbon dioxide and water. But if the supply of oxygen is restricted, this process of decomposition is stopped half-way as it were. The complex constituents of the wood or coal are broken down into simpler bodies, but in the absence of oxygen they are not completely burned away.

It is these intermediate simpler substances which are important in the present connection. Some of them

are gases, and these may be passed away or burnt for heating purposes ; others are vapours which, on cooling, condense to form tar and other liquids. The solid residue remaining in the retorts forms, in the case of the wood, charcoal, and in the case of the coal, coke.

With wood, the chief product of such a "dry" distillation, other than charcoal and a relatively small amount of wood tar, is a dark, red-brown liquid termed "pyroligneous acid." This consists largely of weak acetic acid, but contains also methyl alcohol, acetone, and other bodies.

To obtain the methyl alcohol, the pyroligneous liquor is neutralized with lime and distilled. The lime combines with the acid to form calcium acetate (acetate of lime ; "grey acetate"), which remains behind in the still ; the methyl alcohol, mixed with much water, distils over. In order to remove the water and acetone (which also distils over), the distillate is redistilled. The crude wood spirit thus obtained is finally rectified until the desired degree of purity and strength is reached. To eliminate the last small quantities of acetone and other impurities, the product is treated with various chemicals—lime or soda, sulphuric acid, bleaching powder, and chlorine—and then again rectified.

Most of the methyl alcohol distilled from wood is not very highly purified. It is sold as crude wood spirit or commercial "wood naphtha." Much of this is employed as a solvent in the manufacture of varnishes, lacquers, rubber solutions, and similar products. Another important application of wood naphtha is as a denaturant of ethyl alcohol used for industrial purposes. In some respects it is particularly suitable for denaturing industrial alcohol, since the impurities it contains help to make the spirit unpotable, whilst the methyl alcohol is readily detectable in the denatured spirit,

and thus serves to "earmark" the latter and prevent its illicit use in beverages. At the same time the acetone which it contains, and which is by far the largest of the impurities, does not, in general, prevent the industrial spirit from being used in manufacturing operations.

Wood naphtha is usually produced at about 94 per cent strength (by volume), but this includes a good proportion of acetone, ranging from 10 to 20 per cent or more. When used as a solvent, there is no objection to even the larger proportions of acetone, since this latter is itself a good solvent for resinous bodies. For use as a denaturant, wood naphtha in this country must not contain more than 12 grams of acetone per 100 cubic centimetres, or approximately 15 per cent by volume. In France, however, a minimum of 25 per cent is required.

Besides this crude wood spirit, a more highly-rectified and refined product is made for commercial use, containing from 97 to 98 per cent of true methyl alcohol, and only 1 per cent, or less, of acetone. This quality is employed in large amounts for making formaldehyde, a substance used in the aniline dye industry, and also as a disinfectant. (The antiseptic product known as "formalin" is a solution of formaldehyde in water; it contains from 38 to 40 per cent of formaldehyde.) In the United States and in Canada this more highly-purified quality of methyl alcohol is sold under various trade names, such as "colonial spirits," "Columbian spirits," and "standard wood spirits."

In addition to their use for making formaldehyde, the purer grades of methyl alcohol find considerable application in the preparation of "intermediates" for the manufacture of coal-tar dyestuffs. Dimethyl-aniline, for example, is prepared by heating together,

under pressure, methyl alcohol, aniline, and sulphuric acid; the product obtained is used in making the dyes methyl violet, methyl orange, malachite green, and others. Dimethyl sulphate, made from methyl alcohol and sulphuric acid, is another example of a methyl alcohol derivative used in the making of dyes.

Various compounds used as flavourings and perfumes are also prepared from methyl alcohol. Examples of these are methyl benzoate ("Niobe oil") and methyl salicylate (artificial oil of wintergreen). The latter is employed to some extent in medicine, as well as in perfumery.

Although methyl alcohol of a high degree of purity is an ordinary commercial article, the "absolute" chemically-pure compound is just as rare as the truly absolute ethyl alcohol. Like the latter, it is practically never required except for scientific investigations, and is then specially prepared by chemical processes. It is a colourless liquid, with a spirituous odour, boiling at 66° C. (150·8° F.). Its specific gravity at 15° C. (59° F.) is 0·79647, water at the same temperature being taken as unity.

Mixtures of methyl alcohol and water have nearly the same specific gravities as the corresponding mixtures of ethyl alcohol and water. Hence, for approximate purposes, the alcohol table already given (p. 83) can also be used for finding the strength of aqueous solutions of methyl alcohol.

The main sources of supply of methyl alcohol are naturally the countries where wood is plentiful. Hence it is not surprising to find that a large quantity is made in the United States. During the war, in fact, our supplies were drawn almost entirely from that country and Canada. A relatively small quantity is made here. Much larger quantities are produced in Austria, Hungary,

and Germany; and the industry is being developed in Australia to some extent. The varieties of wood chiefly used for distillation in America are beech, birch, maple, oak, and thorn.

Care should be taken not to confuse wood spirit or methyl alcohol with the ordinary (ethyl) alcohol which can also be obtained from wood. The former is produced, as just described, during the direct (dry) distillation of wood; the ethyl alcohol is obtained by first converting the cellulose substances of wood into fermentable sugars through the action of acids, then fermenting these sugars with yeast, and distilling off the resulting ethyl alcohol. The latter, however, when obtained from wood, usually contains a very small quantity of the methyl product.

There is one important respect in which methyl alcohol differs from ordinary alcohol. It is distinctly more poisonous. Many fatal cases have occurred, chiefly in the United States and in Germany, through the drinking of methyl alcohol, either alone or mixed with ordinary spirit. In one case at Berlin a factitious "schnapps" was concocted by mixing 4 parts of methyl alcohol with 1 part of ethyl alcohol; this was drunk by a large number of people, with very serious consequences. Ninety-five of the participants were taken ill, and 70 of them died. A usual symptom of methyl alcohol poisoning in fatal cases is the occurrence of blindness, which comes on a few hours before death.

The name "methyl alcohol" was given to the liquid under discussion by MM. Dumas and Péligot, who made a careful examination of it in 1834, and pointed out its resemblance to ordinary alcohol. It has, however, been known since the seventeenth century, when Boyle showed that it could be separated from "pyroligneous acid" by distilling the latter substance over burnt

coral. Boyle termed the alcohol "adiaphorous spirit," in reference to its neutral character, as compared with the acid liquid from which it was obtained.

(2) **Higher Alcohols.** Closely associated with ordinary alcohol are certain other bodies of the same chemical type, but differing in some of their properties both from ethyl alcohol and from one another. It was mentioned in Chapter II that, in distilling off the alcohol from a fermented mash, one of the objects achieved by the "rectifier" column of a patent still was the separation of "fusel oil" from the alcohol. This fusel oil is a mixture of various substances; but its main constituents are four alcohols which, since they contain a larger number of carbon atoms in the molecule than ordinary alcohol does, are often referred to as "higher" alcohols.

These are produced, during fermentation, by the action of yeast upon certain nitrogenous bodies which are present in the materials of the mash. The proportion of fusel oil formed is relatively very small—only about 0·5 per cent of the alcohol produced, on the average. The actual quantity, however, is by no means inconsiderable, and the oil itself is of some commercial importance, as is also one of the four higher alcohols which it contains.

These four alcohols are termed (1) propyl, (2) isobutyl, (3) active amyl, and (4) inactive amyl, alcohols. The last two are usually classed together as "amyl alcohol," No. 4 being, however, the larger constituent.

Propyl alcohol is very similar to ordinary (ethyl) alcohol, but has a greater specific gravity (0·80765) and a higher boiling point. Isobutyl alcohol and the two amyl alcohols have still higher boiling points, and differ from the ethyl and propyl members in possessing a rather disagreeable "fusel oil" odour and in having

a less mobile, more oily, character, as well as in being much less soluble in water.

The following table will serve to summarize the formulae, boiling points, and specific gravities of these higher alcohols in comparison with those of the lower members of the alcohol class—

TABLE VIII

PARTICULARS OF VARIOUS ALCOHOLS

Name.	Chemical Formula.	Boiling Point °C.	Specific Gravity 15·6°/15·6° C.
Methyl Alcohol	$CH_3{\cdot}OH$	66·0	0·7965
Ethyl Alcohol	$C_2H_5{\cdot}OH$	78·3	0·7936
Normal Propyl Alcohol	$C_3H_7{\cdot}OH$	97·4	0·8076
Isobutyl Alcohol	$C_4H_9{\cdot}OH$	108·4	0·8062
Active Amyl Alcohol	$C_5H_{11}{\cdot}OH$	128·7	0·8214
Inactive Amyl Alcohol	$C_5H_{11}{\cdot}OH$	131·4	0·8158

It may be mentioned that there are other propyl, butyl, and amyl alcohols known, besides those indicated in the table. Whilst there is only one methyl alcohol, and only one ethyl alcohol, there are two propyl, four butyl, and no fewer than eight amyl alcohols known to chemists. These bodies are distinguished one from another by differences in their chemical and physical properties. Only those described above, however, are produced in normal alcoholic fermentation. The others are of interest theoretically, and one of the butyl alcohols is of some practical importance in the manufacture of synthetic rubber, but except for this brief notice we need not further consider them.

But, it may be asked, why are the higher alcohols of fusel oil of interest in connection with ordinary alcohol?

Well, for one thing, they are present, to a small extent, in brandy, rum, and whisky; they help to give

to these beverages the special character which distinguishes them from " neutral " or " silent " patent still spirit. This is especially true of whisky ; and whilst the characteristic flavours of brandy and rum are mainly due to certain other compounds (" esters "), there is no doubt that the higher alcohols also contribute their share. They form, in fact, the greater part of the so-called " secondary constituents " which differentiate these beverages from simple alcohol.

Their presence in brandy, rum, and whisky is due to the fact that these liquors are either distilled in simple " pot " stills, or else in modifications of the pot still ; and in neither case does the apparatus separate the whole of the fusel oil bodies from the spirit, as the patent still does.

Fusel oil itself is chiefly used as a source of the higher alcohols, which are separated from it by a process of fractional distillation. Amyl alcohol is the main product. It is employed for making amyl acetate, which is the chief constituent of the " pear essence " used in flavouring confectionery. A cruder variety of amyl acetate is applied as a solvent for celluloid substances in the manufacture of varnishes and substitutes for leather. Amyl alcohol is also used in laboratory operations, as a solvent for extracting alkaloids and in the analysis of milk. Isobutyl and propyl alcohols have little or no technical application ; their chief use is for laboratory purposes.

CHAPTER IX

MISCELLANEOUS NOTES AND STATISTICS

Detection of Alcohol. To test for alcohol in an aqueous solution the following experiments are commonly made—

(1) About 2 or 3 cubic centimetres of the liquid are taken in a test-tube, and a few drops of acetic acid added. An equal volume of strong sulphuric acid is then carefully mixed with the solution in the tube, and the mixture, already warm through the action of the sulphuric acid on the water, is gently heated a little more. If alcohol is present, a characteristic fruity odour is developed, due to ethyl acetate produced by the combination of the alcohol with the acetic acid.

(2) A few drops of a solution of iodine and potassium iodide in water are added to a little of the liquid to be tested, and the mixture is then warmed. A solution of sodium hydroxide or sodium carbonate is then added, drop by drop, until the colour of the iodine is just barely discharged. On allowing the mixture to stand for some time a light yellow precipitate of iodoform will appear if alcohol was present, even in a relatively small proportion ; whilst in very weak solutions the characteristic odour of iodoform can be detected, although the precipitate may be imperceptible. It is to be noted, however, that this iodoform test is given by acetone under the same conditions, as well as by lactic acid and some other bodies. Hence the result should always be confirmed by the ethyl acetate test, unless it is known for certain that none of these interfering substances can be present.

Mixtures which contain ingredients other than alcohol and water should be distilled before these tests are applied, and the experiments made on the distillate. Moreover, if there are volatile bodies, such as essential

oils, in the mixture, these will also distil over with the alcohol; and though it is not always necessary, it is generally better to separate them before applying the tests for alcohol. To effect this, the distillate is shaken up with powdered salt until it is saturated with the latter, and the oils or other impurities extracted by shaking with petroleum ether. The aqueous salt solution will retain the alcohol. It is run off from the petroleum ether (which will contain the oils, etc.), and again distilled to separate the alcohol. The tests may now be applied to the purified distillate.

Detection of Methyl Alcohol. When a liquid, purified if necessary by the process just described, has been obtained free from other substances except ethyl and methyl alcohols and water, it may be tested for the presence of methyl alcohol in the following manner.

(1) Dissolve a little sodium formate in about two cubic centimetres of water, and add about the same volume of the liquid to be tested. Then pour carefully into the mixture an equal quantity of strong sulphuric acid. On mixing the contents of the test-tube, warming a little more if necessary, an odour of methyl formate, recalling the smell of chloroform, will be developed if methyl alcohol was present.

(2) A similar experiment may be made with sodium salicylate substituted for the sodium formate. In this case the odour produced will be that of methyl salicylate (oil of wintergreen).

(3) The liquid to be tested (about 5 cubic centimetres) is mixed with an equal volume of sulphuric acid (50 per cent strength), and placed in a small flask containing 3 or 4 grams of powdered potassium dichromate and about 5 cubic centimetres of water. After being mixed and allowed to stand a few minutes, the contents of the flask are diluted with an equal volume of water and

distilled. The distillate will contain formic acid if methyl alcohol was originally present. It is neutralized with solution of sodium carbonate, evaporated to dryness, and the residue re-dissolved in a little water. To a portion of the resulting liquid a few drops of silver nitrate solution are added, and the mixture warmed. A black or brownish-black deposit of reduced silver indicates the presence of a formate, and hence of methyl alcohol in the original liquid. This may be confirmed by adding a little mercuric chloride solution to another portion of the solution obtained after the evaporation; on heating, a white precipitate of mercurous chloride is given if a formate is present.

More delicate tests for methyl alcohol are based upon the fact that formaldehyde is produced when the alcohol is oxidized. The details of the method are not suitable for inclusion in a work like the present, but full directions will be found in the author's larger treatise.

Calculations. The following rules are often useful.

(1) To convert percentage of alcohol by volume into percentage by weight.

Multiply by 0·7936, and divide by the specific gravity of the liquid in question.

Example. Suppose we have a diluted alcohol of, say, 50·2 per cent strength by volume. From Table VI we find its specific gravity to be 0·934. Its percentage of alcohol by weight is therefore $50{\cdot}2 \times 0{\cdot}7936 \div 0{\cdot}934 = 42{\cdot}6$.

(2) To convert percentage by volume into grams of alcohol per 100 cubic centimetres.

Multiply by 0·79284. Thus the diluted alcohol in the above example would contain $50{\cdot}2 \times 0{\cdot}79284 = 39{\cdot}8$ grams of absolute alcohol in every 100 cubic centimetres, or 398 grams per litre.

(3) To convert percentage of proof spirit (by volume) into percentage of alcohol by volume.

Divide by 1·7535. Or, for practical purposes, multiply by 4 and divide by 7.

Example. Given percentage of proof spirit 87·8. Then $87·8 \times 4 \div 7 = 50·2$, the corresponding percentage of alcohol by volume, to the nearest first decimal.

TABLE IX

PERCENTAGE OF PROOF SPIRIT AND OF ABSOLUTE ALCOHOL IN BEVERAGES AS SOLD IN THIS COUNTRY

I.—SPIRITS

BEVERAGE.	Proof Spirit, per cent.	Absolute Alcohol per cent by volume.
VARIOUS SPIRITS (*Whisky, Gin, etc.*)—		
At 25 u.p.	75·0	42·8
„ 30 u.p.	70·0	40·0
„ 35 u.p.	65·0	37·1
„ 40 u.p.	60·0	34·3
„ 50 u.p.	50·0	28·6

II.—WINES

BEVERAGE.	Proof Spirit, per cent	Absolute Alcohol, per cent by volume.
Port	35·3	20·2
Sherry	29·5	16·9
Madeira	28·9	16·5
Tarragona	27·2	15·5
Australian Burgundy	24·8	14·2
Italian Red Wine	23·9	13·7
Champagne	23·6	13·5
French Burgundy (red)	22·1	12·6
Californian Burgundy	20·8	11·9
Italian White Wine	20·6	11·8
French Burgundy (white)	20·2	11·6
Bordeaux (white)	19·9	11·4
„ (red)	17·0	9·7
Cider (bottled)	7·4	4·2

N.B.—These wines represent the cheaper brands retailed by grocers. The percentage of spirit naturally varies a little; the figures given are those of a series of analyses made for the Liquor Control Board.

III.—BEERS (1917)

Beverage.	Proof Spirit, per cent.	Absolute Alcohol per cent by volume.	Original Gravity.
Pale or Bitter Ale . .	11·1	6·4	1060·2
London Stout . . .	9·7	5·5	1064·6
Burton Ale . . .	9·4	5·4	1053·2
Light Pale Ale . . .	7·9	4·5	1042·6
Mild Ale (No. 1) . . .	5·8	3·3	1037·8
Porter	4·3	2·4	1041·5
Mild Ale (No. 2) . . .	2·8	1·6	1016·5

These examples, it should be mentioned, represent purchases made at the end of 1917 for the Liquor Control Board. They indicate, therefore, the alcoholic strengths of the various kinds of beer current in war time.

As regards the last column, it may be noted that the "original gravity" denotes the specific gravity of the wort before fermentation. Beer in this country is taxed, not upon the amount of alcohol which it actually contains, but upon the specific gravity of the unfermented wort—which is, in a sense, a measure of the *potential* quantity of alcohol. It does not necessarily follow that beer with a high original gravity will always contain more alcohol than beer of a lower original gravity, because the proportion of alcohol produced will depend on the extent to which fermentation is carried; but speaking broadly, it would be true to say that a high original gravity of the wort generally connotes a high percentage of alcohol in the beer.

Before the war the current alcoholic strengths of beer were appreciably higher than the foregoing, as will be gathered from the summary on the next page.

IV.—BEERS (PRE-WAR)

BEVERAGE.	Proof Spirit, per cent.	Absolute Alcohol, per cent by volume.
English Strong Ale	19·0	10·9
Dublin Stout	12·3	7·0
Burton Pale Ale	12·2	7·0
American Ale	11·5	6·6
London Porter	9·5	5·4
Pilsener Beer	9·2	5·3
English Light Ale (bottled)	9·0	5·1
Munich Beer	8·9	5·1
London Mild Ale	8·1	4·6

Annual Production of Alcohol. In the United Kingdom the total quantity of spirits distilled in each of the five years shown below was as follows—

TABLE X

ALCOHOL DISTILLED IN THE UNITED KINGDOM

Year Ending 31st March.	Proof Gallons.	Equivalent Gallons of Absolute Alcohol.
1910	43,831,007	24,996,293
1912	45,717,249	26,071,994
1914	51,802,468	29,542,321
1916	49,135,199	28,021,210
1918	37,140,668	21,180,874

The increased quantities shown in the years 1914 and 1916 were due to war requirements. The considerable decrease in 1918 was, no doubt, due partly to the cessation of the war, and partly to shortage of raw materials.

In the table on page 105 a summary is given of the approximate annual production of alcohol in pre-war times by the larger countries of the world, with the principal raw materials employed.

TABLE XI

ANNUAL PRODUCTION OF ALCOHOL

Average for the five years 1909–1913

Country.	Million Gallons of 100 per cent Alcohol.		Chief Materials Used.
	Total Production.	Used for Technical Purposes.	
Austria-Hungary	60·6	10·4	Maize, beet, molasses.
France	59·3	14·7	Beet, molasses, fruit, potatoes.
Germany	82·9	34·9	Potatoes, grain, molasses, fruit.
Italy	9·4	2·3	Grain, fruit.
Russia	125·9	8·8	Potatoes, grain.
United Kingdom	26·0	3·9	Grain, molasses.
United States	72·2	5·8*	Grain, molasses.

Consumption of Spirits in the United Kingdom. The table annexed shows the quantities of home-made and imported spirits retained for consumption in this country, with the quantity per head of the population. It does not include alcohol used for making methylated spirit or for other industrial and educational purposes free of duty.

TABLE XII

ALCOHOL CONSUMED IN THE UNITED KINGDOM

Year.	Home-made.	Imported.	Total.	Home-made	Imported.	Total.
	Millions of Proof Gallons.			Proof Gallons per Head.		
1910	24·4	4·6	26·0	·48	·10	·58
1911	25·3	5·6	30·9	·56	·12	·68
1912	25·4	5·5	30·9	·56	·12	·68
1913	25·3	5·4	30·7	·55	·12	·67
1914	26·8	5·8	32·6	·58	·13	·71
1915	27·8	6·5	34·3	·60	·14	·74
1916	28·9	6·6	35·5	·63	·14	·77
1917	18·8	5·2	24·0	·41	·11	·52
1918	10·3	4·4	14·7	·22	·09	·31
1919	11·9	3·7	15·6	·26	·08	·34

* Average for 3 years.

Industrial Alcohol. In normal times the quantity of methylated spirit produced in the United Kingdom is about 4,500,000 of bulk gallons yearly. Of this, mineralized methylated spirit constitutes rather more than one-third, the remainder being the "industrial" variety. Thus for the five years 1910 to 1914, inclusive, the average annual quantity of the mineralized spirit sent into consumption by makers was 1·66 millions, and of the industrial spirit 2·89 millions of bulk gallons.

In addition to the foregoing, approximately 660,000 proof gallons of alcohol *per annum* (= 377,000 gallons of absolute alcohol) were used during the same period for particular manufactures and in teaching and research; this alcohol was either specially denatured or used in a pure condition without denaturants.

Imports and Exports. In normal times the imports of "plain" spirits (not sweetened or flavoured) into the United Kingdom amount to about 500,000 to 750,000 proof gallons, chiefly from Germany and Russia. But during and since the war our principal overseas supplies came from the United States, Canada, and latterly Natal; and the quantities have been somewhat larger.

TABLE XIII

PLAIN SPIRITS IMPORTED

Country.	Proof gallons.		
	1917.	1918.	1919.
United States	741,871	142,477	195,588
Canada	788,912	2,807	2,806
Natal	—	257,158	971,734
Other countries	72,488	45,097	1,253
Total	1,603,271	447,539	1,171,381

The appearance of Natal as an exporter of alcohol to this country is noteworthy, in view of the question

of obtaining "power" alcohol from British overseas possessions (p. 75).

Imported whisky (American and Canadian) is included in the above quantities of "plain" spirits. Most of the alcohol, however, was used for industrial purposes, and is not included in the table showing the consumption of imported spirits in this country (p. 106).

As regards exports, the quantity of home-made alcohol sent abroad in normal times is about 10,000,000 proof gallons annually. This does not include methylated spirit, of which no export particulars are available.

Revenue from Spirits. The average net receipts from spirits in the United Kingdom during the ten years 1910–1919 were 21·5 million pounds yearly. For the last five years of this period the figures are—

Year.	*Amount.*
1915	£25,274,505
1916	26,838,794
1917	18,014,506
1918	10,596,462
1919	24,242,156

Of these amounts, approximately four-fifths were contributed by home-made spirits, and the remainder by imports. The returns for the years 1917 and 1918 were exceptionally low, on account of war conditions.

Rates of Duty on Alcohol : United Kingdom. These rates vary, of course, from period to period, according to the Budget requirements.

Excise Duties, May, 1922—

	£	s.	d.	
Beer, of original specific gravity 1055°	5	–	–	per 36 gallons.
Cider and Perry			4	,, gallon.
Spirits—				
Warehoused for 3 years or more	3	12	6	the proof gallon.
,, ,, 2 to 3 years	3	13	6	,, ,, ,,
Not warehoused, or warehoused for less than 2 years	3	14	–	,, ,, ,,

In the last two cases, the extra 1s. and 1s. 6d.

respectively are "additional duties" in respect of "immature" spirits. [Unless kept in warehouse for at least three years, spirits are regarded as insufficiently matured.] Such spirits must have been distilled at a strength of at least 60° over proof, and are only delivered to persons authorized to receive them for certain approved purposes (*see* Chapter IV).

Excise duties are levied on home-made products.

Customs Duties (on imported products)—

Beer. The customs rate is 6d. per barrel (36 gallons) more than the excise duty shown above.

Spirits. On plain spirits, and also on Geneva and imitation rum, the customs duties (imperial preferential rates) are 5d. per proof gallon more than the excise duty on spirits. On brandy and rum, the excess above the excise duty is 4d. per proof gallon.

This applies to spirits imported in casks. If imported in bottles, an extra 1s. per proof gallon is charged.

For spirits imported from countries not entitled to imperial preference rates, the customs duties are 2s. 6d. more than the latter rates

Sweetened spirits, liqueurs, and perfumed spirits pay special rates of duty. Thus on perfumed spirits imported in cask the preferential duty is £5 16s. the bulk gallon (not the *proof* gallon), and the "full" rate is £6 the bulk gallon.

Certain imported articles made from alcohol also pay duties of customs, as follows—

	£	s.	d.	
Chloral hydrate		1	9	per lb.
Chloroform		4	4	„ „
Collodion	1	14	11	„ gallon.
Ether, acetic		2	7	„ lb.
„ butyric	1	1	10	„ gallon.
„ sulphuric	1	16	6	„ „
Ethyl bromide		1	5	„ lb.
„ chloride	1	1	10	„ gallon.
„ iodide		19	–	„ „

Wine—	*Full rate per gallon.*	*Preferential rate.*
With not more than 30° of proof spirit	2*s.* 6*d.*	60% of full rate.
With more than 30° but not more than 42° of proof spirit . .	6*s.* 0*d.*	$66\frac{2}{3}$% of full rate.

If the wine is imported in bottle, additional "full" duties of 2s. or 12s. 6d. per gallon, according to whether the wine is "still" or "sparkling," are also levied. The corresponding preferential rates are 1s. and 8s. 9d. per gallon. These heavy additional duties are imposed because the wines in question are, of course, articles of luxury *par excellence.*

ADDENDUM

I

INDUSTRIAL METHYLATED SPIRITS USED FOR MANUFACTURES AND OTHER PURPOSES DURING YEARS ENDED 31ST MARCH, 1920, AND 1921

Quantities used—

1919–20	3,347,089 gallons.
1920–21	2,897,204 ,,

II

SPIRITS: NON-DUTIABLE USE UNDER FINANCE ACT, 1902
(Alcohol (1) *specially denatured*, and (2) *not denatured*)

Year ended 31st Mar.	Use.	Home-made.	Imported.		Total
			Other than Methylic Alcohol.	Methylic Alcohol.	
		Proof galls.	*Proof galls.*	*Proof galls.*	*Proof galls.*
1920	Arts and Manufactures	488,944	357,460	110,646	957,050
,,	Scientific (Universities, Hospitals, etc.) .	7,242	23	179	7,444
		496,186	357,483	110,825	964,494
1921	Arts and Manufactures	545,671	42,938	148,075	736,684
,,	Scientific (Universities, Hospitals, etc.) .	9,348	41	208	9,597
		555,019	42,979	148,283	746,281

III

ALCOHOL DISTILLED IN THE UNITED KINGDOM

Year Ending 31st March.	Proof Gallons.	Equivalent Gallons of Absolute Alcohol.
1919	27,714,273	15,805,117
1920	40,057,769	22,844,464
1921	47,548,108	27,116,115

IV

Alcohol Consumed in the United Kingdom

Year.	Home-made.	Imported.	Total.	Home-made.	Imported.	Total
	Millions of Proof Gallons.			Proof Gallons per Head.		
1920	17·8	6·4	24·2	·39	·14	·53
1921	15·5	4·7	20·2	·33	·10	·43

V

Plain Spirits Imported

Country.	Proof Gallons.	
	1920.	1921.
United States	1,218,176	334,197
Canada	818,784	159,403
Natal	115,091	33,083
Other Countries . . .	37,361	307,438
Total . . .	2,189,412	834,121

VI

Revenue from Spirits

Year ended 31st March—

1920 .	£58,802,652	Duty on home-made spirits raised during the year from 30s. to 50s. per proof gallon.
1921 .	£71,034,847	Duty on home-made spirits raised during the year from 50s. to 72s. 6d. per proof gallon.

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